Energy Research and Development Division
FINAL PROJECT REPORT

SOLAR ENERGY AND THE MOJAVE DESERT TORTOISE

Improving Decision Support for Reviewing and Planning Proposed Projects

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Prepared by: University of Redlands
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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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ABSTRACT

The southwest US has attracted attention for development of new renewable energy generation. However, these energy development projects may adversely impact natural resources and values in this area, including state- or federally-protected species. In some cases, environmental conflict and project delays have resulted because (1) information on potential impacts and successful mitigation strategies is incomplete; and (2) the increased scale and number of projects has raised concerns about cumulative impacts and the need for alternative mitigation strategies to land acquisition. This project provides a framework for assessing the impact of renewable energy projects on the protected Mojave desert tortoise (*Gopherus agassizii*) and, on the same scale, quantifying the benefits of proposed mitigation strategies.

Researchers developed spatial decision support tools that provide scientific information on potential threats, impacts, and recovery actions affecting desert tortoises in California. Research under this project (1) developed new information on the comparative effectiveness of recovery actions; (2) explored alternative models for quantifying the population effects of habitat fragmentation; (3) refined system models and calculations; and (4) tested the system using data from three solar energy development projects.

Using these tools, planners, and project reviewers can better visualize, evaluate, and monitor the direct and indirect effects of energy projects on the tortoise. Users can input solar energy project footprints and run impact and mitigation calculations. Also, users can determine the types and extent of recovery actions that can be most effective for mitigation. Consequently, this can reduce environmental conflict and permitting delays for renewable energy.

This research supports the Desert Renewable Energy Conservation Plan by identifying mitigation strategies and key areas for desert tortoise recovery. The methods and system framework developed for this project are applicable to other regions, sensitive species (e.g., Mohave ground squirrel), and renewable energy technologies (e.g., wind, geothermal).

Keywords: endangered species, decision support, desert tortoise, GIS, mitigation, spatial analysis, solar energy, recovery actions, population fragmentation, sensitivity, impacts, siting, permitting

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Introduction

Developing alternative sources of renewable energy is a critical goal for California. Energy developments may adversely impact the recovery of state- or federally-protected species, so it is important to have accurate scientific information and effective management actions that promote species recovery and mitigate impacts from proposed projects. For some protected species, such as the Mojave desert tortoise, environmental conflict and permitting delays have occurred, because information on potential impacts and successful mitigation strategies is still incomplete; and the increased size and number of projects have raised concerns about cumulative impacts and the need for mitigation strategies in addition to simply buying and protecting land.

Project Purpose

This project provides planners and regulators with scientific information and online analytical tools for predicting the impacts of proposed solar energy projects on the Mojave desert tortoise and the benefits of alternative mitigation strategies. Building on prior research, the project extended a Desert Tortoise Spatial Decision Support System tool and online Desert Tortoise Recovery Portal, developed with support from the California Energy Commission and the U.S. Fish and Wildlife Service. The project aims to reduce environmental barriers to the timely permitting and deployment of clean energy facilities, both through technical improvements in the operation of the system and in the underlying scientific foundation.

Project Process and Results

The project team improved the system to run faster and better serve the needs of various users. The team also addressed specific information gaps related to threats and the effectiveness of recovery actions, measures of sensitivity and uncertainty for decision makers, and population fragmentation and tortoise density. New data and scientific knowledge strengthened system models and advanced the speed and accuracy of system calculations. This project also improved the accessibility and performance of online tools for calculating spatial (location) and temporal (time) impacts of solar energy development projects, and providing spatially-explicit information on appropriate recovery actions.

Scientific accomplishments of this project included:

- Improving models for recovery actions (such as land acquisition based on the threat of future urban development), and developed methods for comparing the benefits of different mitigation actions;
- Developing a promising new theory-based model for estimating the effects of landscape fragmentation on tortoise populations to address concerns over the cumulative effects of multiple utility-scale energy projects being placed on the landscape;
- Exploring hypotheses related to system estimates of risk against new data about trends in the numbers of tortoises; and

- Improving the ability to report to decision makers about the sensitivity of the impact and mitigation calculations to model assumptions and to measure the possible range in values in the calculations.

Technical accomplishments of this project included:

- Testing the system using three actual solar energy development projects; and
- Enhancing calculation procedures and completed online tools for designing management actions and estimating their mitigation benefits, relative to the impacts of proposed solar energy development projects.

Future research and continued system improvement are recommended to:

- Estimate the risk to local populations based on updated assessments of landscape fragmentation, local threats, and population movement, and how these might be mitigated by recovery actions;
- Model landscape-scale dynamics of population fragmentation and climate change, with a priority emphasis on identifying recovery actions that will be most effective across any likely climate change scenarios;
- Adapt and apply the current decision support framework to other species of concern; and
- Evaluate whether the effectiveness of recovery actions lasts over time, and in particular, whether the cumulative impacts of threats over time overwhelm the expected effectiveness of those recovery actions.

The research approach and models have potential for adapting and applying to other species, regions, and types of renewable energy. The system provides a foundation other researchers may use to build impact assessments to support and guide and educate environmental review of renewable energy development.

Project Benefits

The Desert Tortoise Spatial Decision Support System is helping the State of California to achieve its Renewables Portfolio Standard goals by providing science-based information related to the probable effects of proposed solar energy development projects on this key protected species. Timely access to this information in the environmental review process helps to reduce conflict and avoid impacts that are costly to mitigate, thus keeping energy costs lower for the California ratepayer.

Current and future beneficiaries of this system are planners and project reviewers, including project developers, government agencies, stakeholders, and others tasked with resource management decision-making. This research will also support the implementation of the multi-agency Desert Renewable Energy Conservation Plan by identifying mitigation strategies and key areas for desert tortoise recovery.

CHAPTER 1:
Project Overview

1.1 Project Context

Renewable energy development has recently become an increasingly prominent use of lands in the desert southwest. In May 2001, the President issued an executive order (EO 13212) directing Federal agencies to expedite the review of permits for energy-related projects. In 2005, the Federal Energy Security Policy Act established a mandate to approve 10,000 megawatts of non-hydropower, renewable-energy generation on public lands by 2015, a five-fold increase from the previous level of approximately 1,900 megawatts. In 2008, then California Governor Schwarzenegger signed Executive Order S-14-08, which increased the target for California's renewable-energy portfolio to 33 percent by 2020; this target was codified into law in April 2011 under Senate Bill X1-2.

President Obama established new goals of generating 10 percent of the nation's electricity from renewable sources by 2012 and 25 percent by 2025. To achieve these goals, the Secretary of Interior, in March 2009, issued a Secretarial Order (SO 3285A1) making the development, production, and delivery of renewable energy one of the Department's highest priorities. In October 2009, a Memorandum of Understanding was signed between the Department of Interior and the State of California to help coordinate permitting efforts for renewable energy projects. This Memorandum provided a framework of cooperation for moving projects through the permitting process and also called for the development of the Desert Renewable Energy Conservation Plan (DRECP) to help guide future renewable energy development.

As more and larger renewable energy developments are proposed, land managers and stakeholders are concerned that there are "critical knowledge gaps" in our understanding of the "types and magnitudes of impacts on environmental and public health" of this evolving energy system (California Energy Commission 2014). Major energy development projects can adversely affect a broad array of resources and values, including fish and wildlife, cultural resources, and recreational opportunities (see Hernandez et al. 2014). For certain resources, including endangered species, there are explicit statutory and regulatory drivers requiring mitigation (e.g. Clement et al. 2014; CA Fish and Game Code Section 2081(a)2). Project-by-project compensatory mitigation can be inefficient and ineffective for many reasons. The narrow focus of project-by-project development and associated mitigation can forego the opportunity to consider and address broadly the full impacts of a project and most beneficial mitigation actions. In addition, land acquisition historically has been the mitigation action of choice when offsetting project-by-project impacts; however, the majority of land in the desert Southwest is already under federal ownership, and acquisition opportunities are increasingly limited.

By examining the conservation needs of a more expansive area, such as a landscape or recovery unit, it may be possible to determine how mitigation decisions could more effectively and efficiently compensate for the project's impacts. However, the lack of landscape-scale scientific information, and the tools to use it, can make it difficult to identify and prioritize mitigation opportunities at a greater scale. Also needed is information on the "relative success of mitigation strategies" and "proven mitigation measures" for renewable energy projects (California Energy Commission 2014). If available at the appropriate scale, such information could be incorporated into decision support tools that would help policy makers and managers to better plan landscape-scale mitigation (Clement et al. 2014)

1.2 Project Description

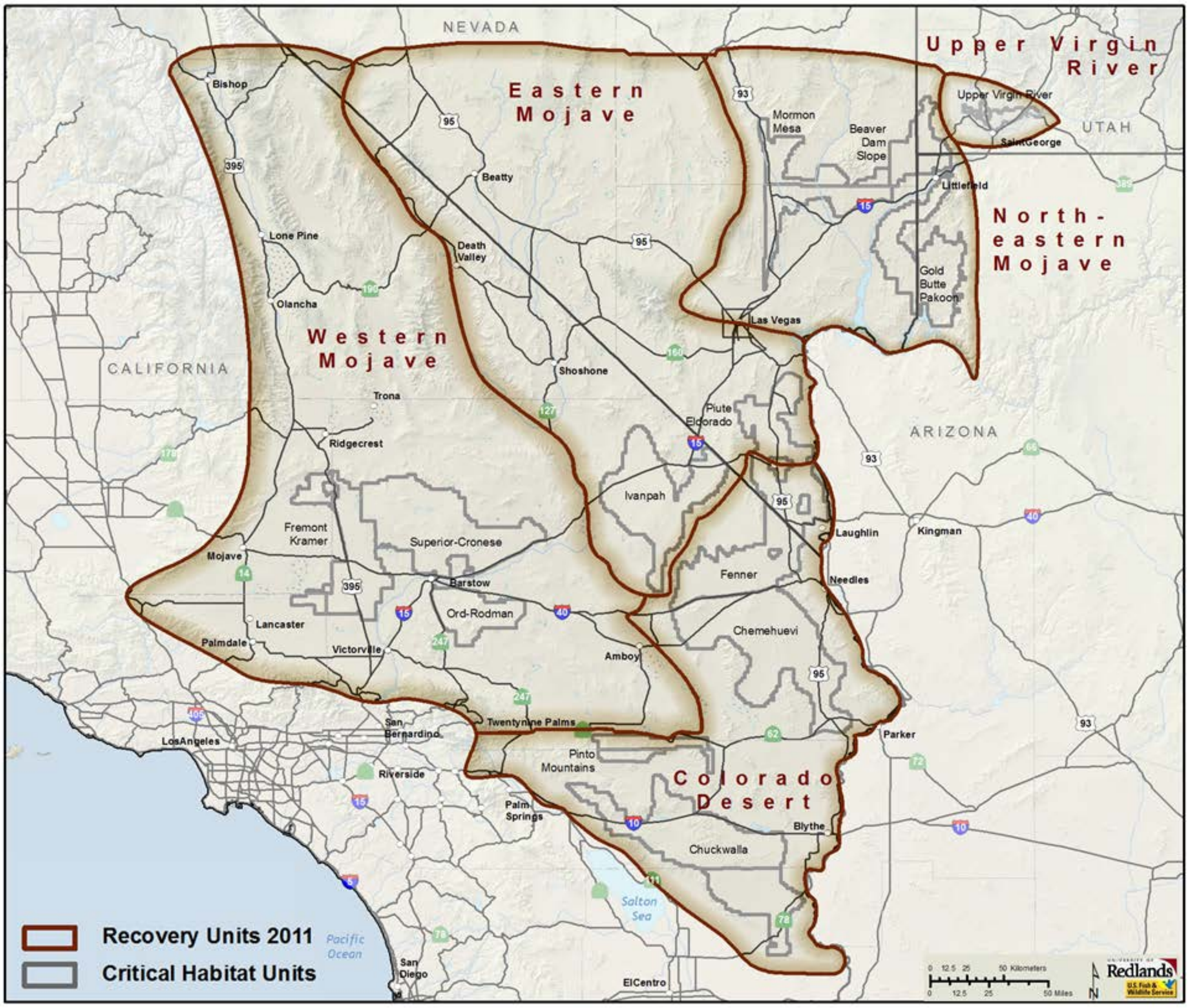
This project provides structured decision support for assessing the impacts of solar projects on the Mojave desert tortoise (*Gopherus agassizii*) and quantifying the benefits of proposed mitigation strategies, particularly those benefits related to off-site management actions needed for desert tortoise recovery.

1.2.1 The Mojave Desert Tortoise

The Mojave desert tortoise is a long-lived, wide ranging species that is central to many conflicts over desert land use. Protected by state and federal laws as a threatened species, the desert tortoise is in decline due to a complex array of threats including direct mortality, habitat loss and habitat degradation (Doremus and Pagel 2001; Scott et al. 2006). The 2011 revised recovery plan (USFWS 2011) identified five recovery units across the range of the species (Figure 1.1). Recovery units for the desert tortoise are special units that are geographically identifiable and are essential to the recovery of the entire listed population, *i.e.*, recovery units are individually necessary to conserve the genetic, behavioral, morphological, and ecological diversity necessary for long-term sustainability of the entire listed population.

Recovery units collectively cover the entire range of the species. Critical habitat and other management designations included within "tortoise conservation areas" are focal areas for recovery within each recovery unit (Figure 1). The 2011 plan identified 17 Tortoise Conservation Areas (TCA; Figure 2 and Table 1) within the recovery units. Tortoise conservation areas capture the diversity of the Mojave population of the desert tortoise within each recovery unit, conserving the genetic breadth of the species, providing a margin of safety for the species to withstand catastrophic events, and providing potential opportunities for continued evolution and adaptive change. Critical habitat that supports the conservation of the species within each recovery unit was also designated under the U.S. Endangered Species Act (Figure 1).

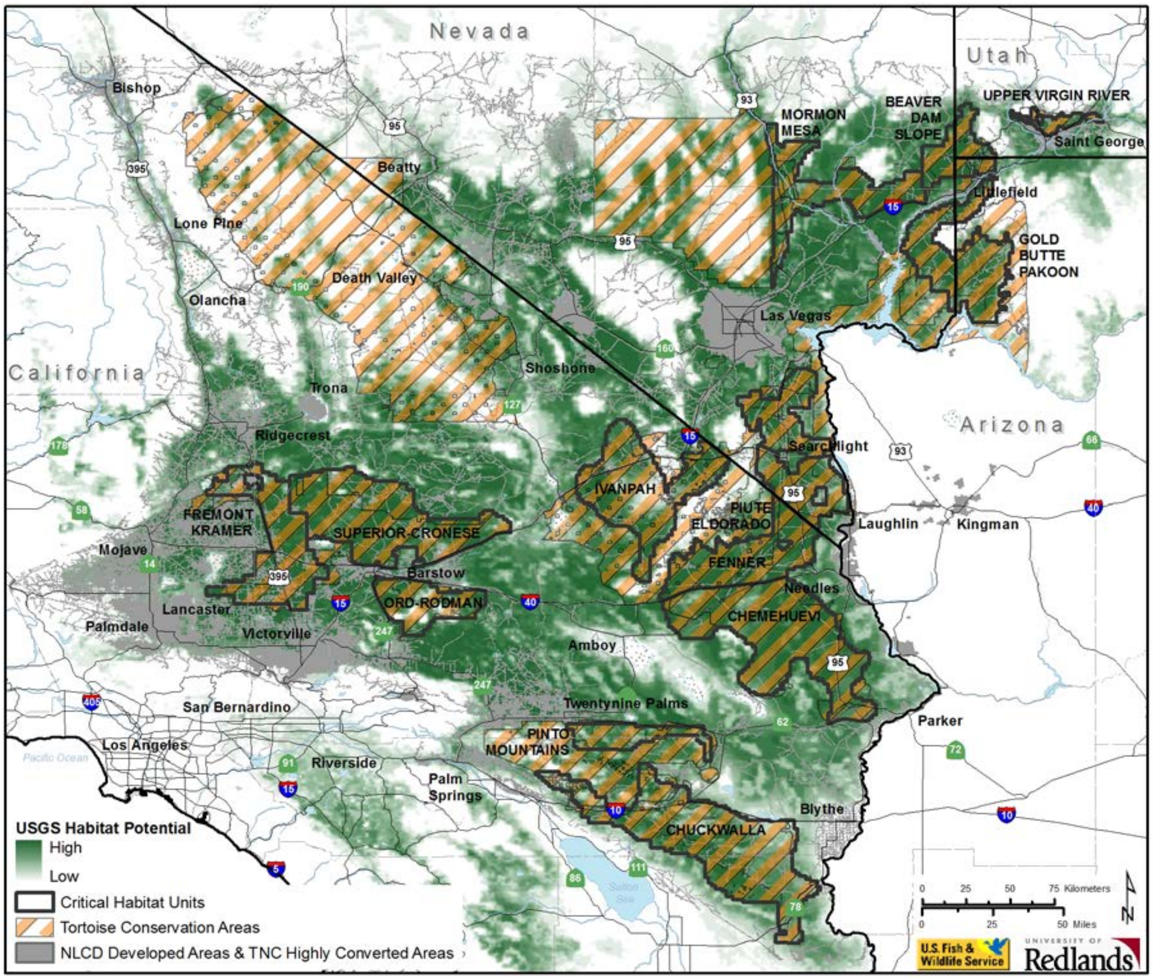
Figure 1: Map of Mojave Desert Tortoise Range, Recovery Units and Critical Habitat Units



A map of the Mojave desert tortoise population range showing designated Recovery Units as of 2011, and critical habitat units. The range includes large areas of California and Nevada, and portions of Arizona and Utah.

Source: USFWS 2011

Figure 2: Map of 17 Desert Tortoise Conservation Areas (TCAs)



A map of the 17 Desert Tortoise Conservation Areas (TCAs) identified in the revised Recovery Plan (USFWS 2011) for the desert tortoise.

Source: USFWS 2011; Averill-Murray et al., 2013

Table 1: 17 Desert Tortoise Conservation Areas (TCAs) Within the Recovery Units

Recovery Unit	Tortoise Conservation Area (TCA)
Colorado Desert	Chemehuevi (CM)
Colorado Desert	Chocolate Mountain Aerial Gunnery Range (AG)
Colorado Desert	Chuckwalla (CK)
Colorado Desert	Fenner (FE)
Colorado Desert	Joshua Tree (JT)
Colorado Desert	Pinto Mountains (PT)
Colorado Desert	Piute Valley (PV)

Recovery Unit	Tortoise Conservation Area (TCA)
Eastern Mojave	Eldorado Valley (EV)
Eastern Mojave	Ivanpah (IV)
Northeastern Mojave	Beaver Dam Slope (BD)
Northeastern Mojave	Coyote Springs Valley (CS)
Northeastern Mojave	Gold Butte-Pakoon (GB)
Northeastern Mojave	Mormon Mesa (MM)
Upper Virgin River	Red Cliffs Desert Reserve (RC)
Western Mojave	Fremont-Kramer (FK)
Western Mojave	Ord-Rodman (OR)
Western Mojave	Superior-Cronese (SC)

Source: USFWS 2011; Averill-Murray et al., (2013)

1.2.2 Decision Support for Analysis of Impacts and Potential Mitigation Actions Related to Alternative Energy Development and the Desert Tortoise

The USFWS and the University of Redlands have developed a Desert Tortoise Spatial Decision Support System (SDSS) that provides access to sound and transparent scientific information on potential threats, impacts, and recovery actions affecting desert tortoises in California. It addresses the need to resolve critical scientific data gaps, including the development of habitat suitability models and relative metrics for mitigation strategies, and provides analytical tools for planning and management of renewable energy development (California Energy Commission, 2014). This allows resource managers to better understand, evaluate, and monitor the direct and indirect effects, beneficial and adverse, of activities and policies on listed species, which can help reduce environmental conflict and permitting delays over renewable energy.

In 2011, the project team received a grant from the California Energy Commission (Energy Commission) Public Interest Energy Research (PIER) program to pursue priority research and key system enhancements that would increase the utility of the Desert Tortoise SDSS for (a) evaluating impacts of solar energy development projects on the Mojave desert tortoise in California; and (b) quantifying mitigation options associated with those impacts. The Energy Commission's Siting, Transmission, and Environmental Protection (STEP) division and the California Bureau of Land Management (BLM) both used the prototype system to conduct preliminary calculations that tested all aspects of the SDSS framework: conceptual modeling, threats data, weights and parameters elicited from experts, and spatial geo-processing (Murphy et al. 2013).

Building on this prototype and prior research, the project team identified key areas for a targeted extension of the system that strengthened the scientific basis for the models and system calculations funded under a second grant from the Energy Commission PIER program. This research further developed and refined the data, models, quantitative analysis, and reporting functionality of the SDSS. The project partners also improved the system's ability to calculate spatial and temporal impacts of solar energy development projects, and to provide spatially-explicit information on appropriate recovery actions. These enhancements provide planners and project reviewers with better knowledge and tools to inform their evaluation of impacts of solar energy development projects and assessment of types and extent of recovery actions that can be most effective for mitigation. Current and future beneficiaries of this system are planners and project reviewers, including project proponents, government agencies, stakeholders, and others tasked with resource management decision-making. This research also supports implementation of the multi-agency DRECP by informing evaluation of mitigation strategies and priority areas for desert tortoise recovery.

1.3 A System for Comparing Impacts and Mitigation

A spatial decision support system is a method for breaking down a large problem into its component parts and identifying how those parts interact (Starfield 1997). Such systems employ computer technologies and involve relationships which use decision rules, models, databases, and formal representations of decision maker's requests to indicate specific actions to solve problems. Use of these systems allows different types and levels of information to be pooled, compared, weighed, and interpreted. Developing and applying a decision support system makes it apparent where information is missing and where there is a need for research or monitoring programs (Starfield and Bleloch 1991).

This project applies a highly structured, iterative methodology that integrates science-based, transparent modeling and spatial data to perform scenario-based evaluation, and to link management alternatives to expected outcomes. The Desert Tortoise SDSS quantifies the impacts of threats to tortoise populations and identifies and prioritizes recovery actions that are most likely to ameliorate those threats (Darst et al. 2013; Murphy et al. 2013). The system can incorporate outputs (data, information, knowledge) from other landscape-scale planning efforts and climate research. The SDSS also is unique in that it can, on the same measurement scale, calculate (1) the negative impacts on species recovery caused by implementation of a proposed project; and (2) the positive effects of proposed mitigation (a portfolio of recovery actions), which allows planners and project reviewers to make direct comparisons for individual projects.

1.3.1 Overview of the System

Models in the Desert Tortoise SDSS analyze:

- The direct and indirect effects of threats to tortoise population declines (i.e., which threats cause other threats, and how these threats increase stresses on tortoise populations); and
- Recovery action-to-tortoise population relationships (i.e., what are the most appropriate actions given a set of population stresses faced by the species).

The system relies primarily on geospatial data of the spatial extent of threats and recovery actions, and the spatial variation in the probability of desert tortoise presence (Nussear et al. 2009; Fry et al. 2011), to calculate changes in risk to tortoise populations. An interactive version of the complete library of geospatial datasets used in the Desert Tortoise SDSS is available online (http://www.spatial.redlands.edu/dtro/dataexplorer/).

The SDSS estimates spatially-explicit risk as the contribution of threats to tortoise population change (Darst et al. 2013) at every point within the range (Murphy et al. 2013). This approach does not estimate the *absolute* change in population, but rather the *relative* contribution of threats or stresses to whatever population change is occurring and thus the contribution to an increase in risk to the population. Changes in risk to desert tortoises can come in the form of

- threat *increase* (e.g., installation of a solar project within tortoise habitat) or
- threat *decrease* (e.g., undertaking a suite of recovery actions within tortoise habitat as part of a mitigation strategy).

All changes in risk result from changes in stresses to the tortoise population and are calculated on a relative scale, and thus are comparable across impacts and recovery actions. The ability to compare the effects of threat increases and recovery actions on the same scale of risk to population is central to the system's utility for informing review of proposed development actions or land use changes in tortoise habitat.

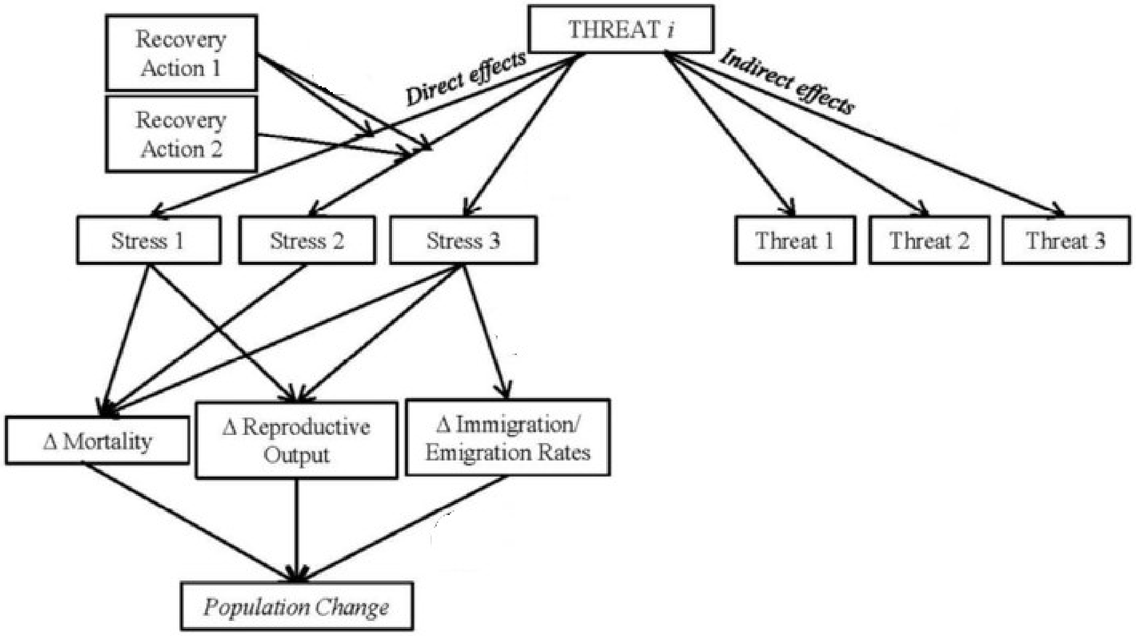
Two foundational components of the Desert Tortoise SDSS are the *conceptual model* and the *computational models*.

1.3.2 Conceptual Model

The *conceptual model* (Figure 1.3) is the backbone of the system (Murphy et al. 2008, Darst et al. 2013), and encapsulates scientific hypotheses about how the complex network of threats and recovery actions affect desert tortoise populations, as recorded in the revised Recovery Plan (USFWS 2011). The model employs a standard lexicon for biodiversity conservation (Salafsky et al. 2008), which defines a list of potential threats, stresses, and conservation actions. This lexicon provides common elements that can be linked in a causal chain to represent a hypothesis about how actions are expected to bring about desired outcomes.

In the conceptual model, each threat is an individual sub-model. The threat sub-models are connected so that the direct and indirect effects of all threats to the species are captured in a single network (Darst et al. 2013; Figure 3). This network includes demographic population effects and two life stages (change in adult mortality, change in juvenile mortality, change in reproductive output, and change in immigration/emigration rates). Linkages in the network indicate relationships that can potentially be affected by application of recovery actions.

Figure 3: Conceptual Model Structure in the Desert Tortoise SDSS



The threats-based desert tortoise conceptual model describes the complex interrelationships of threats to the population, the stresses that are the response of the population to those threats, the population effects that are affected by those stresses, and the recovery actions that may reduce effects of threats.
Source: Darst et al. 2013.

The sub-models included in the system conceptual model are:

1. Threat-based population change models

   - *Threat-to-Threat Interaction Model:* estimates the contribution of a (focal) threat to another threat. For example, the threat of Invasive Plants contributes to the threat of Fire Potential.
   - *Threat-to-Stress Interaction model*: estimates contribution of each threat to population stress. For example, the threat Invasive Plants contributes to the stress of Dehydration.
   - *Relative Stress model*: estimates contribution of each stress to population effects. For example, the stress of Dehydration contributes to a change in the population effect of Juvenile Mortality.
   - *Demographic Impact model*: estimates contributions of population effects to overall population change.

2. Recovery action threat-stress suppression models

    - *Threat-Stress Mechanism model:* threats cause the stress in the population via a mechanism. For instance, the threat of Motor Vehicles on Paved Roads causes the stress of Crushing through the mechanism of On-Road Collisions.

    - *Recovery Action Effectiveness model*: estimates the amount of a threat-stress mechanism that the implementation of a recovery action suppresses. For instance, the recovery action of Erecting Tortoise Barrier Fencing along both sides of a road prevents the tortoises getting on to the road, and so eliminates the danger of On-Road Collisions.

The project partners previously elicited *weights* from a variety of experts for every link in the conceptual model (Darst et al. 2013). For most links, a weight indicates the relative contribution of that node to the node to which it and others contribute (e.g., the contribution of a threat to a particular stress relative to the other threats that contribute to that same stress). Twelve desert tortoise biologists estimated the relative contribution of an increase in severity of a particular threat by 10 % over 10 years on the severity of other threats. Tortoise biologists who participated in the threat-to-threat assessment were experts chosen based on their experience applying regulations to address how threats (e.g., Urbanization, Solar Energy Development, or Roads) contribute to other threats (e.g., Invasive Weeds, Ravens, or Human Access). A separate group of twelve experts used a similar process to evaluate the relative contribution of threats to each stress. These experts were active Mojave desert tortoise biologists with experience and awareness of current research on mechanisms by which threats degrade conditions such as nutritional quality, extent of habitat loss, or predation rates specific to tortoises. In the threat-to-threat assessments, the experts were asked to estimate the range-wide (rather than a sub-region they were most familiar with) contribution of one threat to another threat, of a threat to a stress, or of a stress to population effect.

To quantify the weights for the relationships between population effects and overall population change, the project partners used elasticity values from an existing population viability analysis for desert tortoises (Doak et al. 1994) that was adjusted to reflect one reproductive and one non-reproductive life stage (Darst et al. 2013). The effectiveness of recovery actions was then estimated on a 5-point scale, where 5 indicated the recovery action would fully ameliorate the stress caused by a threat, and 0 meant the recovery action would have no effect. The effectiveness of recovery actions for the desert tortoise remains largely unknown (GAO 2002; Boarman and Kristan 2006; USFWS 2011). Therefore, we estimated the predicted effectiveness of recovery actions at reducing each stress caused by a particular threat under two recovery action scenarios: best case effectiveness (high-end) and worst-case effectiveness (low-end).

All of these conceptual relationships and weights are captured, managed and documented using a Conceptual Model Manager tool. In the tool, users can explore the strength of the model linkages (interactions) and literature citations that provide evidence for the existence of the relationship. The Conceptual Model Manager displays a representation of the threats-based desert tortoise conceptual model and could be utilized for other species (Figure 4; http://www.spatial.redlands.edu/cmm/).

Figure 4: Conceptual Model Manager Tool

The Conceptual Model Manager provides a visualization of the components and knowledge contained in the conceptual model. All of the conceptual relationships in the Desert Tortoise SDSS can be represented and managed using this online tool.

Source: Desert Tortoise SDSS Conceptual Model Manager Tool, http://www.spatial.redlands.edu/cmm/

1.3.3 Computational Models

The *computational models* in the system implement aspatial and spatial (geoprocessing) analysis calculations based on the knowledge and data defined in the conceptual model (Murphy et al. 2013). The three essential system computations are:

1. Estimation of *baseline risk* to the desert tortoise from existing threats within the study area.

2. Estimation of *increase in risk* to the tortoise from proposed, new increases in threat in the study area.

3. Estimation of *decrease in risk* to the tortoise resulting from site-specific, potential recovery actions.

The Desert Tortoise SDSS employs the following spatial representation and computational models.

1. *Threats Spatial Representation Model*: uses geospatial data to represent where, and with what intensity, threats occur geographically.

2. *Recovery Actions Spatial Representation Models*: provides a spatial representation for all recovery action types of where, and with what intensity, a site-specific recovery action occurs.

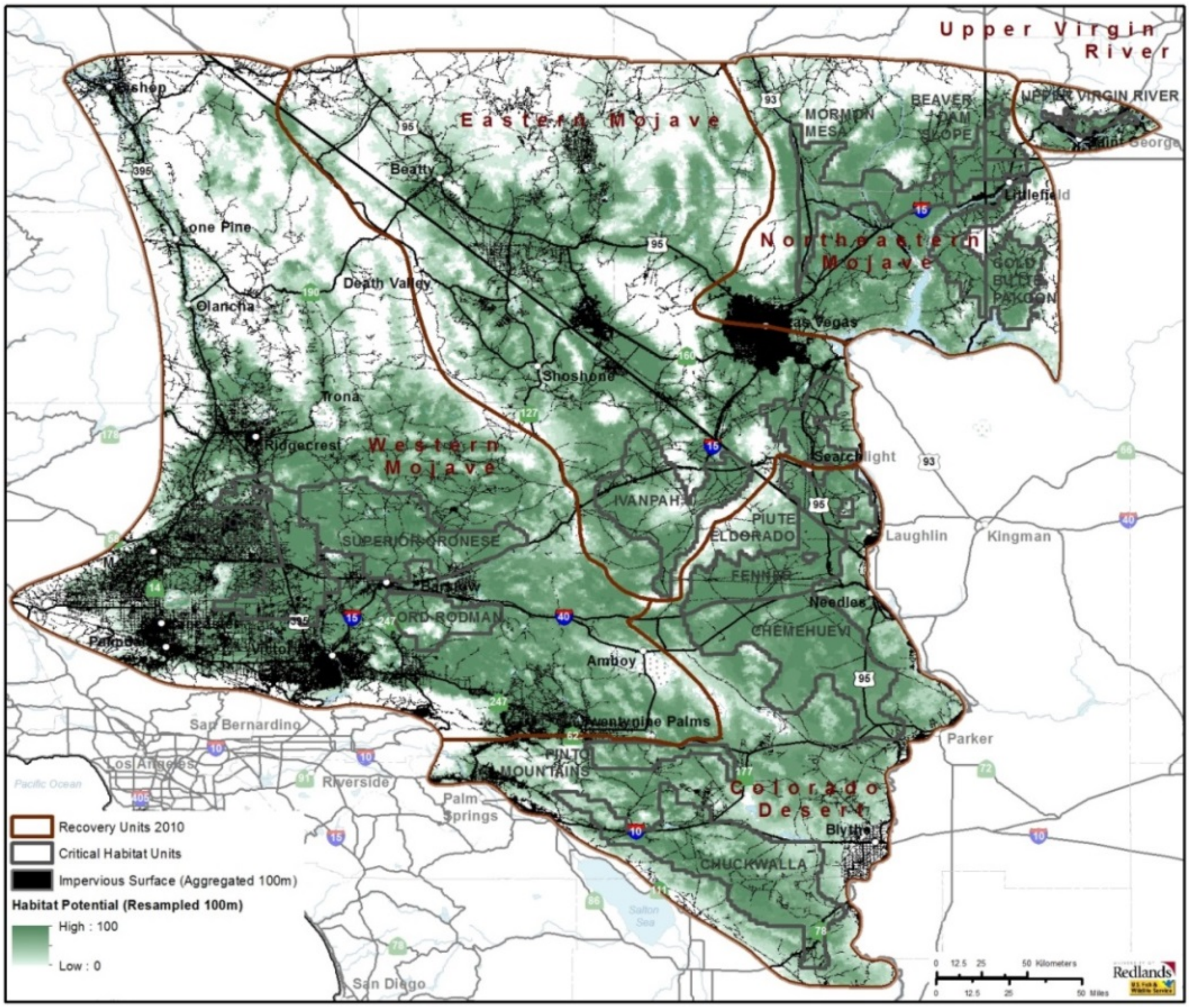
3. *Spatial Computational Models*

   - *Spatial Threats-based Population Change Model*: combines spatial data with a weighted network computational model of threat to stress and stress to population models, to estimate the contribution to population change from all threats at every point on the range.

   - *Risk to Population Model*: modifies the contribution of threats to population change by the probability of whether a tortoise is likely to occur at that location on the landscape. This *probability of presence* surface is calculated by removing impervious surface from the USGS desert tortoise habitat potential surface (Figure 5). This ensures that risk is not assigned to areas on the landscape where tortoises do not live now and will not live in the future.

   - *Recovery Action Effectiveness Model*: estimates effectiveness of recovery actions in suppressing threat-stress links (i.e., mechanisms).

Figure 5: Probability of Presence Map Layer for Mojave Desert Tortoise



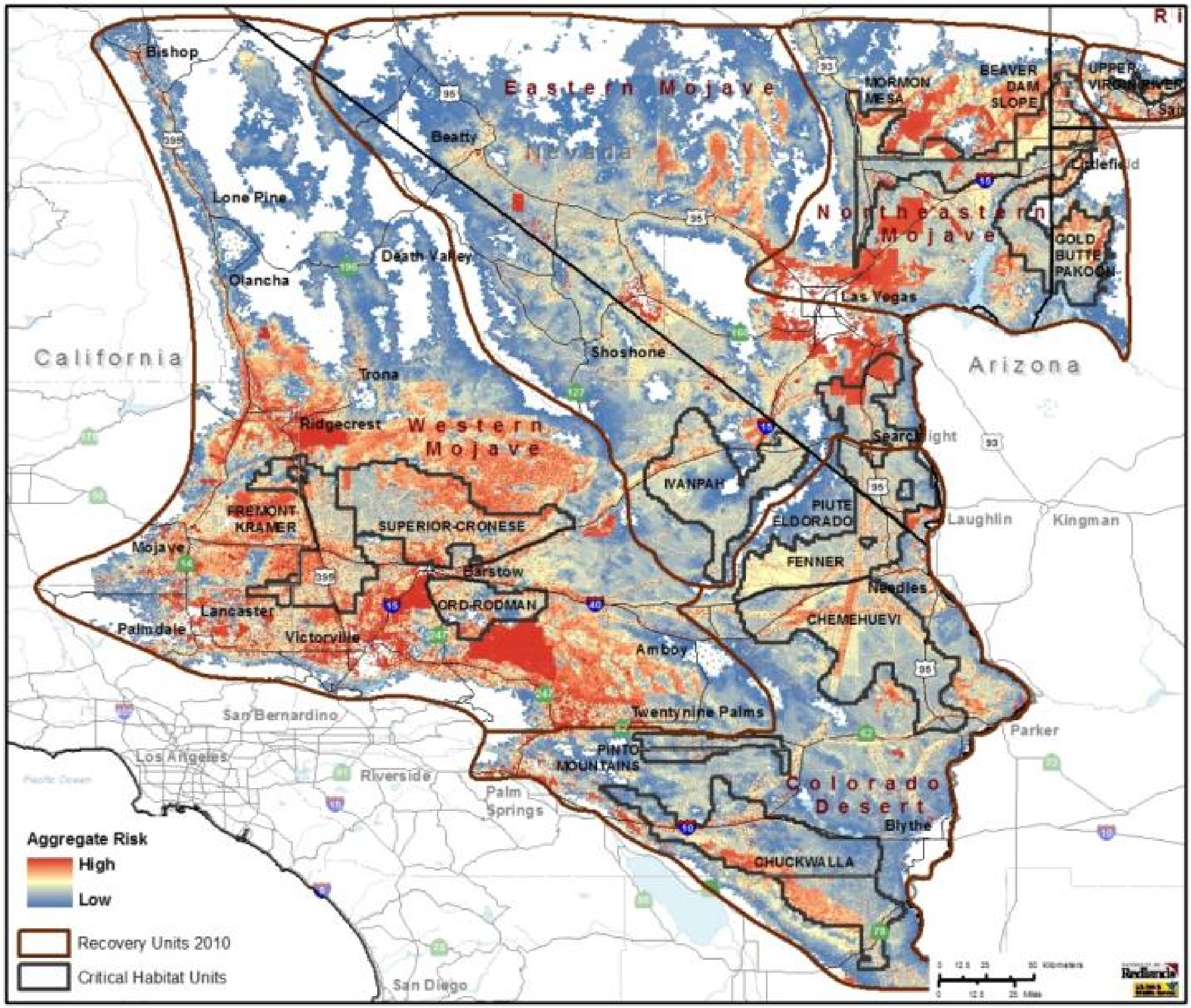
To estimate current probability of tortoise presence, the project partners used the U.S. Geological Survey (USGS) habitat potential model (Nussear et al. 2009). The USGS model reflects historic or pre-human-altered habitat potential based on environmental variables. From this, the team subtracted “impervious surfaces,” as defined by the National Landcover Dataset (Fry et al. 2011).

Source: Desert Tortoise SDSS

These computational sub-models are employed in the three main spatial computational processes of the system, as follows:

1. *Spatial Computation of Risk to Population:* executes the Threat-based Population Change computation and multiplies its output at every point by the probability of presence at that point, to estimate the Risk to Population (*baseline risk;* Figure 6).

Figure 6. Baseline Aggregate Risk to Population Map Layer



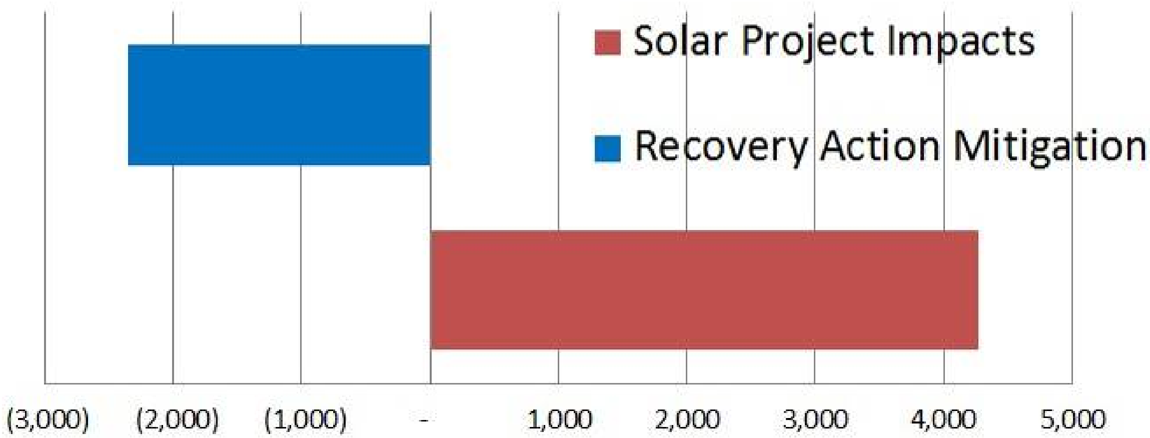
This map shows baseline risk from current threats, calculated by the system for the entire desert tortoise range. Red is higher risk; blue is lower risk to the tortoise population.

Source: Desert Tortoise SDSS

2. *Spatial Computation of the Change in Risk to Population due an Increase in a Threat:* enumerates all the direct and indirect paths by which the Threat Increase affects the stresses in the population, and then executes the relevant subparts of the Population Change computation model to estimate the total change (*increase)* in Risk to Population.
3. *Spatial Computation of the Change in Risk to Population due to a Recovery Action:* enumerates all the threat-stress relationships affected by the recovery action and executes the Recovery Action Effectiveness models for each of them. The resulting decreases in stresses are aggregated to estimate the total change (*decrease)* in Risk to Population.

The impacts on the desert tortoise due to a new threat and the mitigation value of a suite of recovery actions are both estimated as a change in the Risk to Population layer. For calculations run against the same input threats data, conceptual model, and probability of presence data, the changes to Risk to Population can be summarized aspatially on the same scale (Figure 7).

Figure 7: Summary of Changes in Risk to Population From the Desert Tortoise SDSS



Change in risk to the tortoise population based on a hypothetical solar energy project proposal, and a proposed suite of recovery actions that could be implemented in the surrounding area.

Source: Desert Tortoise SDSS

1.3.4 Uncertainty Analyses

The Desert Tortoise SDSS is a complex computational system, whose outputs depend on both the input threat datasets and the many weights and parameters that describe the risk model. Different values for the inputs (i.e., weights and parameters, collectively, the system components) would likely result in different estimates of change in risk to the tortoise population. Although the system uses the best available data for weights and parameters, these estimates are not precisely known. Thus there is uncertainty in the outputs and sensitivity of those outputs to the various inputs of the system.

Sensitivity analysis explores the question of to which model components' variability (e.g., variability in inputs, weights, and/or parameters) the system outcome uncertainty is most sensitive (Saltelli et al. 2010). Knowing this will aid future efforts to reduce the variability in those components and to efficiently reduce the output uncertainties. *Uncertainty analysis* focuses on quantifying the uncertainty in the outcomes, using error bars on the outcome values. Sensitivity analysis and uncertainty analysis are both used in the approach called Output Variance Decomposition (Saltelli et al. 2010).

Work completed under the first Energy Commission grant indicated that a global spatial sensitivity analysis approach was computationally feasible, despite the complexity of the model and the size of the desert tortoise range. Two key improvements were funded by the second grant to produce error bars for both the increase in risk from the solar project and decrease in risk from a suite of site-specific recovery actions. These improvements were: (1) to characterize the variability of more of the system components, and (2) to generate order of magnitude faster calculations that makes feasible the tens of thousands of simulation runs needed to generate the uncertainty of proposed solar projects.

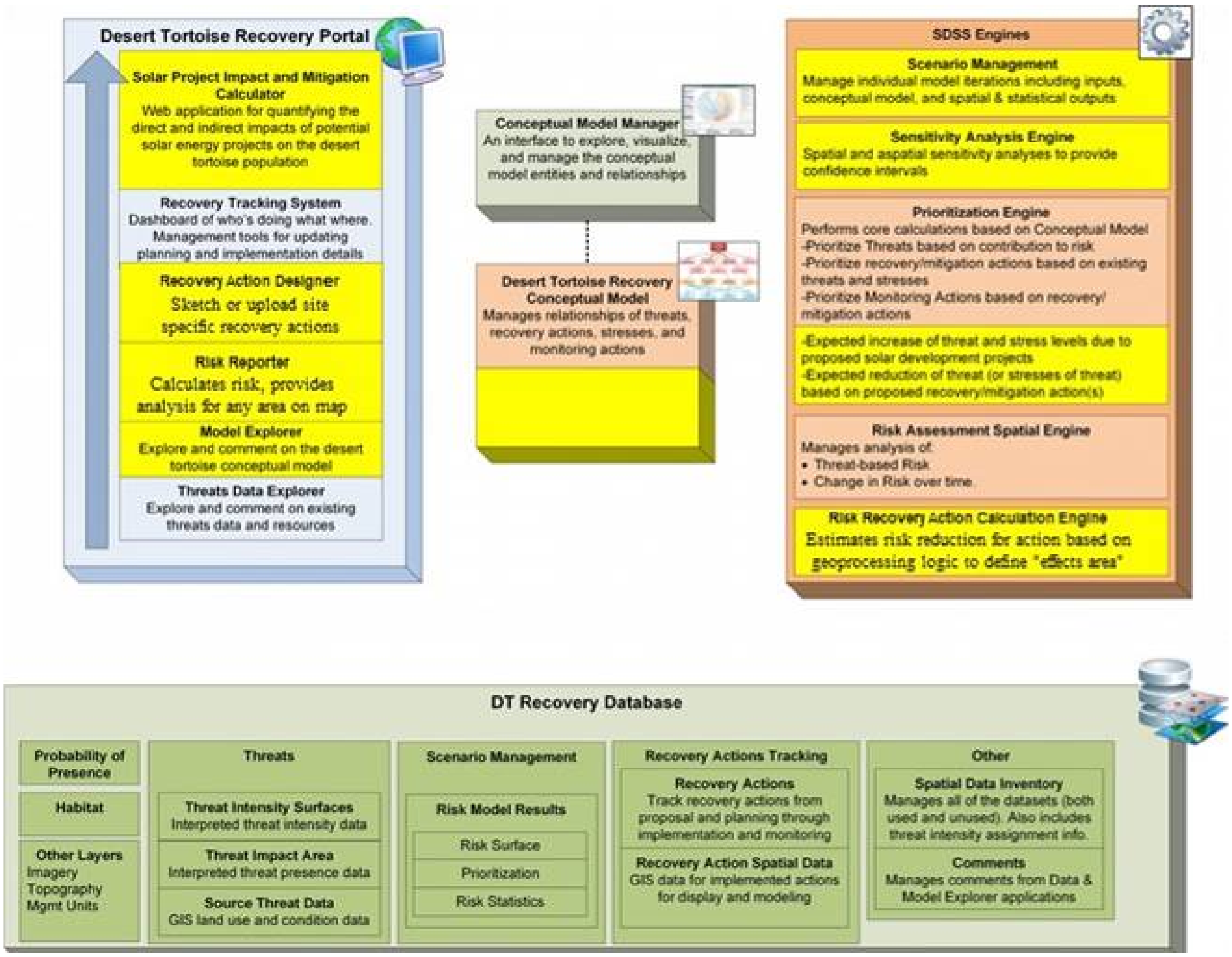
To facilitate uncertainty analyses, the project team developed a Spatial Sensitivity Analysis (SSA) module for the system. The SSA module provides estimates of the variability in a subset of the system's components and calculates the uncertainty in outputs based on repeated (40,000) runs of the system, when those values are varied as Monte Carlo simulations. The project partners varied: (1) the expert weights that characterize threat-stress-population effects contributions as being described by normal distributions with a standard deviation of 25%, and (2) the estimated effectiveness of recovery actions at ameliorating the effects of threats to the tortoise as again being described by normal distributions with a standard deviation of 25%. Not allowing for variance in all components of the system means that the uncertainty estimates for the outcomes must be treated as minimum estimates.

1.4 Iterative System Improvement Strategy

Developing and improving the science, models, and data in the SDSS occurs iteratively. The project partners strive for continuous improvement of the system based on research findings, system performance, and feedback from experts and advisors at each iterative phase of development. Needs identified from each phase of system development form the basis for the next round of iterative system improvement.

With the first Energy Commission grant, the project partners extended the underlying models in the SDSS to estimate the increase in risk to the desert tortoise resulting from modeled implementation of proposed solar energy development projects in the California Mojave Desert (for a complete description, see Murphy et al. 2013). Figure 8 shows the system architecture at the end of this first project. The system consists of a Desert Tortoise Recovery Database that provides services to system components, organized into three functionality stacks: Conceptual Model Manager, SDSS Engines and a web-based Desert Tortoise Recovery Portal.

Figure 8: Desert Tortoise SDSS System Architecture



The Desert Tortoise SDSS architecture consists of four major technology stacks: database, engines, conceptual model, and recovery portal. Those components of the stacks highlighted in yellow were developed under the first Energy Commission project.

Source: Desert Tortoise SDSS; Murphy et al. (2013)

From this architectural perspective, the important components of the Desert Tortoise SDSS as of the first Energy Commission grant included:

- *Conceptual Model*: the stored model of entities and relationships and spatial calculation instructions.
- *SDSS Engine*: the geospatial processing engine that executes spatial calculations as directed by the conceptual model.
- *Data Explorer*: public web tool that displays all key datasets used for download and review.
- *Model Explorer*: public web tool that displays conceptual model for access and review.

- *Solar Project Impact and Mitigation Calculator*: an online tool that calculates and displays impacts of proposed energy development plants and associated management action packages.
- *Desert Tortoise Recovery Action Portal*: an online, restricted site housing the Solar Calculator, Data and Model Explorers.

A critical part of the first Energy Commission project was analyzing the SDSS inputs, outputs, model structure, model content, and sensitivity to parameters and inputs, in order to identify priority improvements in the next system iteration. The project partners also examined overall workflow and performance for running calculations of solar energy development impacts and corresponding recovery action mitigation packages. In addition, the team considered the knowledge sharing and collaboration tools associated with the project. Where applicable, results from the aspatial sensitivity analysis were used to prioritize findings. Table 2 below summarizes the priorities for system improvement that became the focus for this second Energy Commission funded project.

Table 2: Prioritized Areas for System Improvement in Second Project

General Area	Specific component	Gaps identified from 1st project	Priority improvements for 2nd project
Collaboration tools	Data Explorer	Need for a publically accessible online tool for data sharing. Provide further description of raw and derived threats data sets.	Develop a Data Explorer tool that provides access to and sharing of these input spatial data layers. Annotate those layers with a comprehensive metadata set.
Conceptual Model, Threat/Stress Submodels	Conceptual Model, SDSS Engine	Sensitivity analysis showed that population fragmentation was an important contributor to overall risk estimates, yet our submodel for the contribution of threats to population fragmentation did not account for the population-level effect of the impact.	Research and establish a new submodel for population fragmentation that (a) reflects current scientific knowledge and literature; (b) provides for the unique aspects of desert tortoise corridors; (c) incorporates geometric impacts of habitat destruction/degradation; and (d) is calculable at the range scale. Integrate this submodel with SDSS Engine.

General Area	Specific component	Gaps identified from 1st project	Priority improvements for 2nd project
Conceptual Model, Recovery Action submodels	Land acquisition recovery type	Need to improve how land acquisition is represented in the conceptual model, to better characterize the benefits from acquisition by incorporating the landscape-level variation in potential for future development.	Research and develop a new model that incorporates the potential for development in the threat of urbanization, and integrate with land acquisition recovery action.
Conceptual Model, Overall Model Structure	Conceptual Model Manager/SDSS Engine	Need to upgrade conceptual model to adequately model the interaction between habitat degradation and probability of presence.	Based on literature, attempt to develop a model where the probability of presence changes with habitat degradation/restoration.
Computational models and workflows, for Developers	Desert Tortoise Recovery Action Portal	Provide a means for project developers to input specific recovery actions for mitigation.	Create a Recovery Action Designer tool, where developers can create, upload, or edit site-specific recovery actions. Integrate this into the existing Desert Tortoise Recovery Portal.
	Solar Project Impact and Mitigation Calculator (Calculator)	Provide a means for project developers to add new recovery actions to a particular mitigation package and calculate reduction in risk.	Integrate a new Recovery Action Designer tool into the Calculator workflow that permits addition of new recovery actions and calculates reduction of risk.
Computational models and workflows, for Regulators	Calculator	Provide a means to generate a report of the results from the Calculator.	Add a report generator function to the Calculator.
Computational models and workflows, for Researchers	Calculator	Allow researchers to rerun calculations for an older, specific set of input datasets, model structures, and SDSS engine version. This capacity is critical for analyzing improvements in the system.	Create a Scenario Manager tool where specific group of input data sets, model structures, and SDSS engine version are tagged to a calculation run. Allow saved Scenarios to be specified in later runs of the Calculator.

General Area	Specific component	Gaps identified from 1st project	Priority improvements for 2nd project
Uncertainty Analysis	Spatial Sensitivity Analysis module	Ability to understand which components of the model have the greatest contribution to spatial results.	Develop a full spatial sensitivity analysis (SSA) capability that shows the relative impacts of weights, input threats and probability of presence to risk estimates.
	Uncertainty estimates	Developers and regulators need to have uncertainty estimates for risk estimates.	Need to characterize variation in components, so that when combined with SSA, can provide uncertainty estimates for system outputs.

Source: Desert Tortoise SDSS

1.5 Approach of the Current Project

This project focused on improving modeling of recovery actions and the effects of population fragmentation; system testing, for which the project team and the Energy Commission selected three existing solar energy projects as study areas (the Ivanpah Solar Energy Generating Station (ISEGS) project, the Genesis Solar Energy project, and the Blythe Solar Power Project); exploring hypotheses about trends in desert tortoise numbers; and improving the overall system workflow. Subsequent chapters provide detailed methods and results for each of these focus areas.

1.5.1 Chapter 2 Recovery Actions and Effectiveness

There is a lack of sufficient, suitable private land for acquisition in the Mojave to mitigate for the projected impacts of development activities on desert tortoises. Therefore, a goal of this project was to better understand how other recovery actions compare to land acquisition, and to each other, in terms of their relative effectiveness in mitigating risk to the tortoise. This chapter describes how the project team developed a new spatial data layer for the potential threat of future development to quantify the unique benefits of land acquisition. From this the system could calculate ratios of different recovery actions, relative to land acquisition, in reducing risk to tortoise populations in a given area.

A related objective of the project was to provide a means for users to spatially define and evaluate effectiveness of specific recovery actions as part of a mitigation package. This chapter briefly describes activities undertaken to develop and integrate tools and data that provide this functionality. Further details on how these new data and tools fit into the overall Desert Tortoise SDSS are provided in Chapter 6.

1.5.2 Chapter 3 Model Improvements and Population Fragmentation

From analyses under the previous grant, the project partners recognized that population fragmentation is an important consequence of utility-scale solar energy development, and considered improvements to the conceptual model related to how fragmentation affects risk to the tortoise population. This chapter explores alternative approaches to estimating fragmentation effects and how these may be integrated in the SDSS impact calculations.

The desert tortoise does not lend itself to many traditional fragmentation models. However, using meta-population theory the project team was able to capture connectivity aspects important for the tortoise through the metric of *population capacity,* using a new map layer for *altered habitat potential* that quantifies *resistance* to tortoise movement across the entire range. This chapter outlines the approach taken, using this new metric and a traditional *probability of connection* metric for three alternative energy development scenarios in the Ivanpah Valley study area.

1.5.3 Chapter 4 System Testing: Solar Calculations and Uncertainty Analysis

Using the three existing solar energy projects and their associated mitigation packages, the project partners tested changes to the workflow, system interfaces, input data, and underlying models. This included calculating baseline results for the SDSS and identifying three changes to the system model that would substantially change outputs compared to the baseline: (1) introduction of potential urbanization, (2) updated population fragmentation sub-model, and (3) updated impervious surface in the *probability of presence* layer used in impact calculations.

Another project objective was to further the uncertainty analysis pioneered in the previous grant. including: (a) applying the existing spatial sensitivity analysis (SSA) of the weights, both one at a time (OAT) and collectively via a Monte Carlo approach, to estimate a lower bound of variance in (a) the total impacts, and (b) total mitigation for the proposed 2011 ISEGS project.

1.5.4 Chapter 5 Exploring Hypotheses About Trends in Adult Tortoise Density

Newly available desert tortoise density data provided an opportunity to use the SDSS and statistical analysis to explore hypotheses about what affects trends in adult desert tortoise populations in conservation areas, and at what scales.

The project partners framed several initial hypotheses related to tortoise abundance (both densities and trends) on a subset of the most important threats datasets in the population dynamics of conservation areas, such as overall risk as estimated in the SDSS*, altered habitat potential*, recovery action implementation, and landscape-wide factors such as precipitation and drought. The predictive power of each hypothesis was then computed and compared.

1.5.5 Chapter 6 Improving Workflow and Usability of the System

This chapter describes key changes and enhancements made during this project, to continuously improve the data, workflows, calculations and user experience of the system. It notes improvements to data management, archiving, display and reporting, including new spatial datasets and standardization of metadata, as well as improved data accessibility. A series of figures illustrate the updated architecture of the existing Desert Tortoise Recovery Portal, as well as two new tools added during this project: (1) the *Recovery Action Designer*, which allows users to sketch or upload designs for site-specific recovery actions and calculate risk reduction based on mitigation packages, and (2) the *Desert Tortoise Risk Explorer*, which permits users to sketch an area polygon (such as a potential solar energy development site), and explore what factors are contributing to risk within that project area.

1.5.6 Chapter 7 Conclusions and Gap Analysis for Future Research

This chapter highlights priorities for future development of the Desert Tortoise SDSS. It describes how this research relates to the desired objectives of the Energy Commission's EPIC Triennial Investment Plan to resolve critical gaps in scientific data, and develop analytical tools that support the appropriate siting and planning of renewable energy development by providing a comprehensive and comparative view of impacts and mitigation strategies. The SDSS also promotes the development of efficient and effective compensatory mitigation programs for unavoidable impacts, in support of the science-based, landscape-scale approach called for in the recent Department of Interior Mitigation Strategy (Clement et al. 2014).

1.5.7 Appendices

Appendix A provides a complete data inventory for the geospatial datasets in the Desert Tortoise SDSS. Appendix B contains a copy of a report provided by the project team to the Renewable Energy Action Team on Sept 12, 2013, and referenced in Chapter 2: *Applying a Spatial Decision Support System to Calculate Mojave Desert Tortoise Mitigation Action Ratios for the Desert Renewable Energy Conservation Plan*. Appendix C includes additional details on system improvements made to the Desert Tortoise SDSS as part of this project.

More information on the system, its datasets, conceptual and computational models, are provided in the Final Report from the previous grant (Murphy et al. 2013), and through the online Desert Tortoise Recovery Portal tool, found at: http://www.spatial.redlands.edu/cec/.

CHAPTER 2: Recovery Actions and Effectiveness

This chapter describes work undertaken as part of this project to improve the design, modeling, and calculations of population effects related to recovery actions. By providing project developers with an improved workflow and more accessible and accurate information about potential recovery actions that could be included in specific mitigation packages, the project partners aimed to improve efficiency in the project review process.

Recovery actions are management actions that may be taken in support of desert tortoise recovery (Darst et al. 2013), such as those actions that might be included in an off-site mitigation package for a renewable energy project. Two activities were undertaken to enhance system utility by improving models and workflows related to recovery actions:

1. Improving the model for the land acquisition recovery type to account for the potential threat of future development; and

2. Providing a means for users to define site-specific recovery actions for inclusion in a mitigation package, and to calculate the resulting reduction in risk to the tortoise population.

These project activities were supplemented by two concurrent efforts to develop recovery action definition and tracking that were funded by USFWS:

1. Leveraging information developed by desert tortoise Recovery Implementation Teams (RITs) for site-specific recovery action plans (http://www.fws.gov/nevada/desert_tortoise/documents/recovery_plan/20140508.ca.mojaverit_recoveryactionplan_v1.pdf). Region-specific lists of prioritized recovery actions from the RITs were incorporated into the SDSS, to improve model calculations and identify potential effects of recovery actions.

2. Developing a methodology and online toolset (a *Recovery Action Tracking* tool and database) to facilitate design and storage of additional site-specific recovery actions for analysis, approval, and integration, and enable comparison of project impact and recovery value of mitigation action pairs.

This chapter describes improvements to the Desert Tortoise SDSS workflow and models, and online tools developed and integrated to provide this functionality. Further details on how these tools fit into the overall system architecture and user workflows are in Chapter 6.

2.1 Improved Model for the Recovery Action of Land Acquisition

Land acquisition historically has been the mitigation action of choice when offsetting project impacts. Therefore improving the accuracy of how the Desert Tortoise SDSS estimates the reduction in risk to tortoises from land acquisition was an explicit objective of this project. Quantifying the benefits of land acquisition as a recovery action requires different methods compared to other recovery actions, because acquisition eliminates a *potential threat* of future development, where other recovery actions reduce *current threats* already on-the-ground (such as relinquishment of grazing, restoring habitat, or closing roads). The project partners used projection scenarios for future development in California, and the variation in conservation importance of private parcels, to develop a new data layer representing the risk to the tortoise from the potential threat of future development. This became the *threat intensity layer* upon which the recovery action of land acquisition could be quantified. The project team then tested this method for calculating the recovery benefits of land acquisition using the three study solar energy development projects: the Ivanpah Solar Energy Generating Station (ISEGS) project; the Genesis Solar Energy project; and the Blythe Solar Power Project.

2.1.1 A New Approach for Modeling the Recovery Action of Land Acquisition

The recovery action of land acquisition involves taking an undeveloped parcel within tortoise habitat and protecting it from future development. The original model for land acquisition in the SDSS took into account: (1) the area of the parcel, (2) the probability of presence for the tortoise over that area, and (3) whether the parcel fell within a protected tortoise conservation area (TCA), or a habitat connectivity corridor. For Mojave solar energy development projects, parcels that are available for land acquisition are private lands that are both likely to be developed and represent value to the desert tortoise by being in a TCA or habitat corridor. The project team accounted for this likelihood of development by incorporating (a) the probability that any parcel may actually be developed; and (b) how eliminating this potential threat can decrease risk to the tortoise.

2.1.2 Method to Estimate the Value of the Recovery Action of Land Acquisition

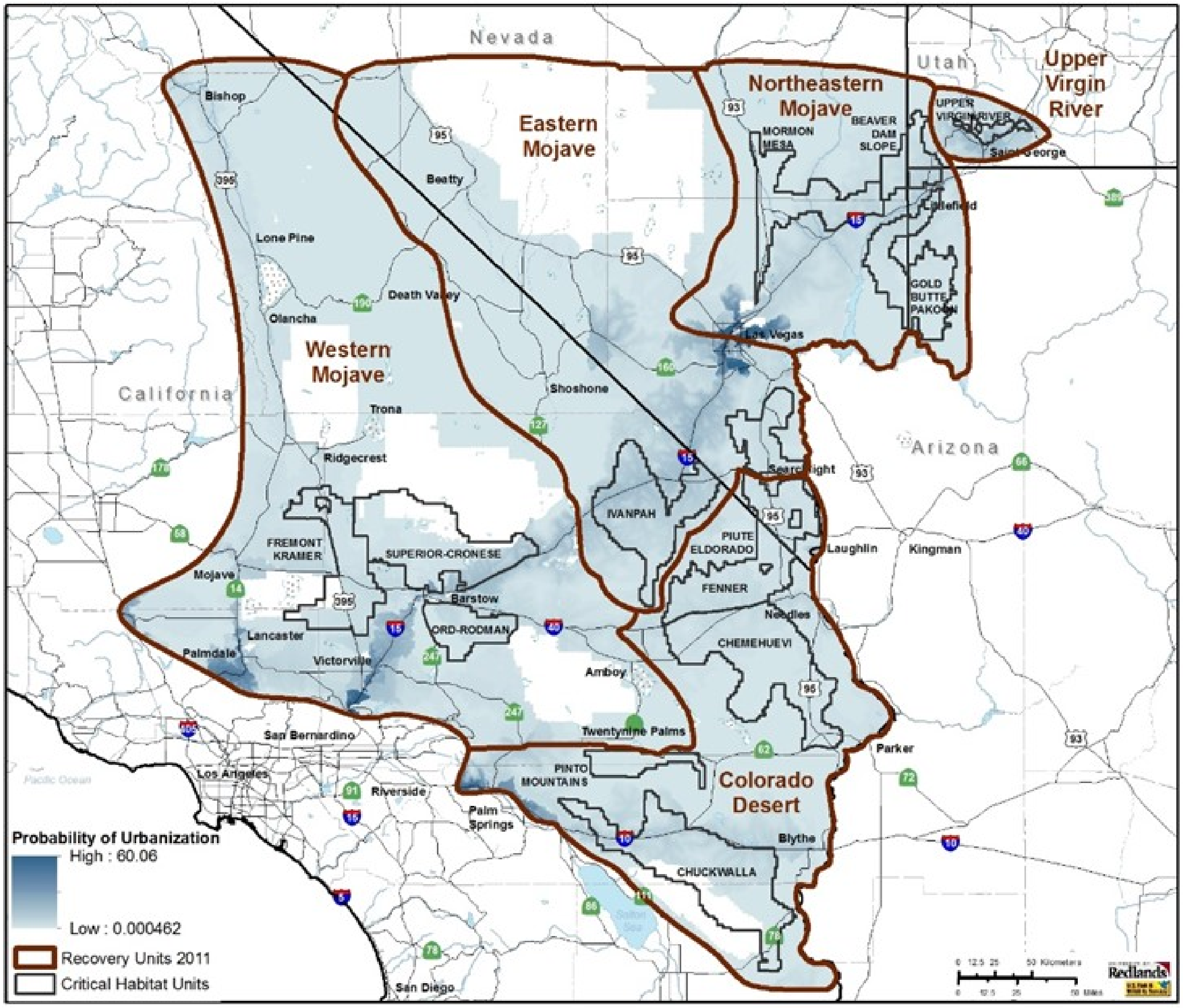
2.1.2.1 Step 1: Estimating Increase in Risk Posed by Potential Urbanization

In the SDSS model, a parcel of private land that has no current protection represents a *potential* threat to the desert tortoise. If that parcel is developed, it becomes an additional area in the urbanization layer, and contributes an increase in risk to the tortoise population. To estimate the decrease in risk resulting from land acquisition and eliminating that potential threat of development, the project partners borrowed an approach from decision tree theory. The first step was to estimate the expected increase in risk to the population posed by potential urbanization, in terms of the probability of parcel development, the expected increase in risk due to urbanization (as a *potential urbanization threat* map layer), and the probability of tortoise presence on each parcel.

After pursuing several alternatives, the project partners decided to use the human access layer generated by Theobald (2008) as a proxy for potential urbanization. The team chose this approach because (a) it uses access by road a key predictor, which includes more of the tortoise's range than urban expansion models typically include; and (b) Theobald's layer was calculated for all areas of the full desert tortoise range in CA, AZ, NV and UT. The use of human access as a proxy for potential urbanization was tested in two ways: (1) qualitatively against current urban development represented in the National Land Cover Database (NLCD 2006), and (2) quantitatively through linear regression against Landis and Reilly's (2003) Urban Footprint Model which projects urban expansion through 2050.

Several input spatial data layers, including private lands, potential conversion, probability of urbanization (Figure 9) and current urbanization, were used to derive a new layer of *future* potential urbanization threat (Figure 10).

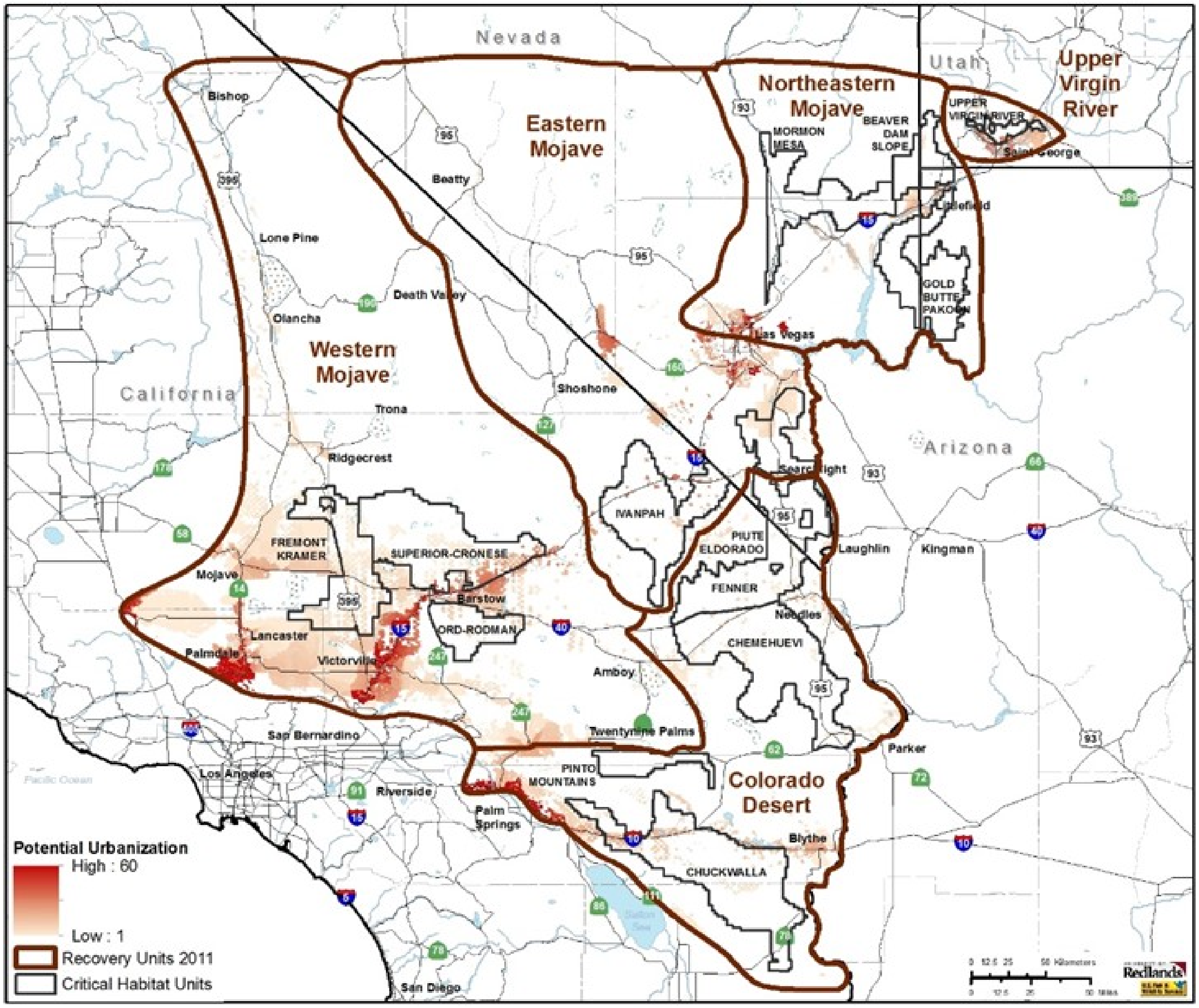
Figure 9: The Probability of Urbanization Map Layer



The probability of urbanization mapped for entire desert tortoise range. The numbers represent percent probability of an area being developed by year 2050.

Source: Desert Tortoise SDSS

Figure 10: Future Potential Urbanization Threat Map Layer



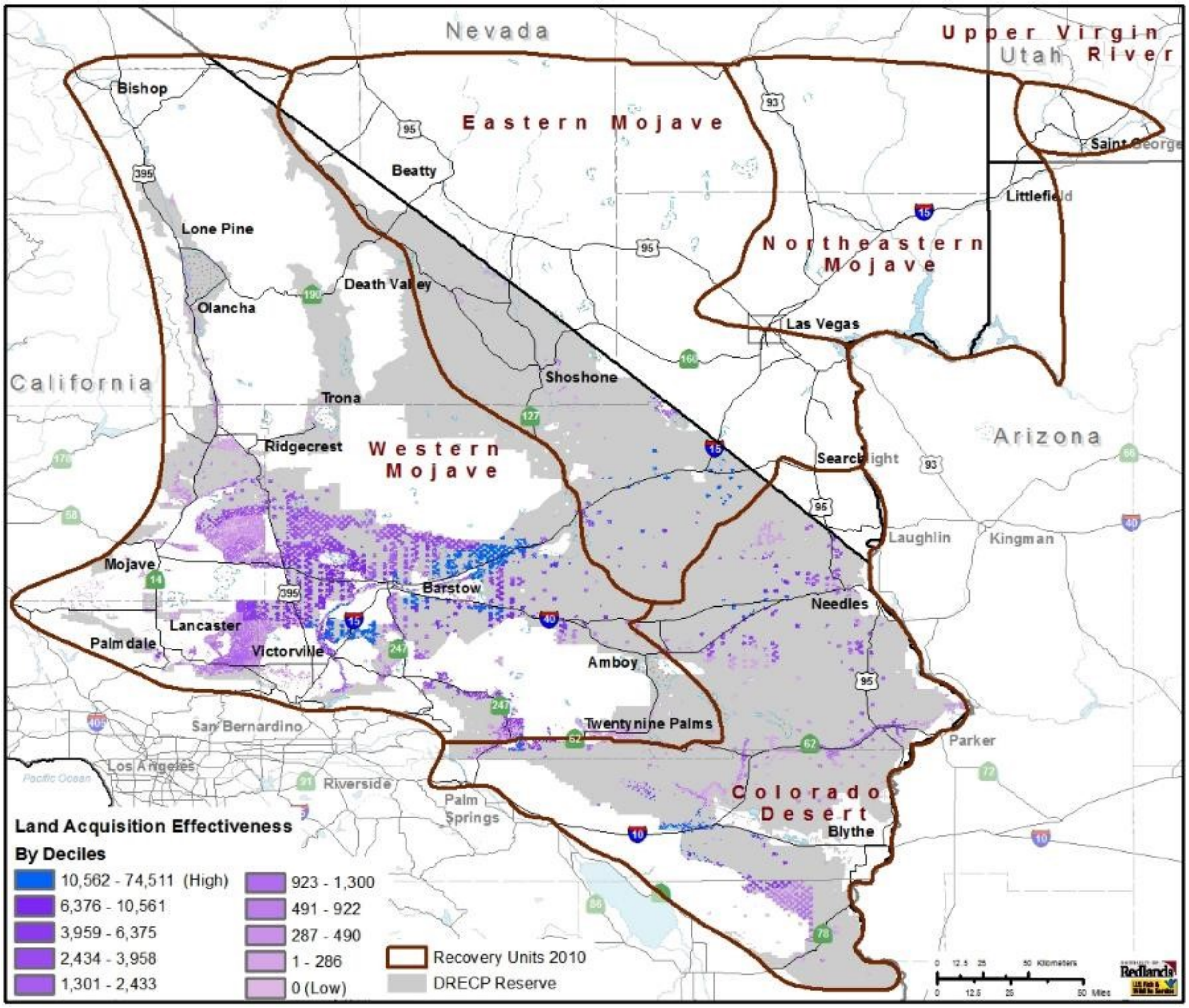
Map of threat of potential urbanization of private lands in the tortoise range. The map does not show where potential risk to the tortoise is highest, but where the threat itself is highest.

Source: Desert Tortoise SDSS

2.1.2.2 Step 2: Estimating Decrease in Risk From Land Acquisition

The second step in estimating the recovery value of land acquisition was to calculate the reduction in risk from land acquisition. If a private parcel with development potential is acquired, the value of that action is the full or partial elimination of the expected increase in risk from development. The recovery action is considered fully effective when the acquired parcel is 100% protected (in Tortoise Conservation Areas), 75% effective when in protected Corridors and 50% effective elsewhere. The project partners conducted geoprocessing using the potential urbanization layer, the contribution to aggregate risk, and probability of presence layer in order to derive a map of the value of land acquisition in reducing risk to the tortoise population over the entire range (Figure 11).

Figure 11: Land Acquisition Effectiveness Map Layer



Map of the effectiveness value of Land Acquisition for private lands in the California portion of the desert tortoise range. The grey area represents the proposed reserve area under the preferred alternative in the draft Desert Renewable Energy Conservation Plan.

Source: Desert Tortoise SDSS

The effectiveness of land acquisition as a recovery action varies across the landscape. Parcels with the highest likelihood of being developed, with the best tortoise habitat, inside tortoise conservation areas are the most valuable for acquisition. Parcels that are unlikely to be developed, have low habitat potential, and are outside of conservation areas or linkages are least valuable to tortoise recovery. The methods and results described above have significantly improved the characterization of the risk of potential development of private lands, and thereby achieved a better estimate of the value of land acquisition to desert tortoise recovery.

2.2 Relative Effectiveness of Recovery Actions

Having a more robust way of quantifying the benefits of land acquisition also provided the ability to more accurately compare the relative benefits of other recovery actions amongst themselves and against land acquisition. The project partners estimated the relative effectiveness of five other recovery actions in a report for the Renewable Energy Action Team (REAT), summarized here (for the complete report, see Appendix B). The method involved calculating: (1) baseline risk to the desert tortoise from existing threats in the three recovery units in California, (2) the decrease in risk to the tortoise resulting from potential recovery actions implemented within the DRECP reserve area (an envelope for potential conservation that was delineated in the preferred alternative of the draft Desert Renewable Energy Conservation Plan (DRECP 2014); see grey area in Figure 2.3) for each recovery unit, and (3) the variance in the mitigation ratios associated with estimates of decrease in risk. The project partners found that the relative values of recovery actions varied among recovery units; therefore it was necessary to provide recovery unit-specific values of how much of each recovery action equates to the same decrease in risk to the desert tortoise. In addition, the project team found that for different areas, the decrease in risk for the *same* recovery action type could vary by orders of magnitude: where a specific management action is implemented matters. Therefore, to compare the relative effectiveness of two different recovery actions, the team needed to develop a method to handle the variance in both.

The efficacy of each recovery action in reducing risk to the tortoise population was quantified as an *effectiveness weight* in the SDSS (Darst et al. 2013; Murphy et al. 2013). For all recovery actions, the project partners followed the guidance in the revised recovery plan for the tortoise (USFWS 2011) that recovery efforts should be focused:

- First, within designated tortoise conservation areas, where actions were scored as 100% effective at contributing to recovery;
- Second, within the identified linkages (Averill-Murray et al. 2013), where actions were scored as 75% effective at contributing to recovery; and
- Third, in tortoise habitat outside of these linkages, where actions were scored as 10% effective at contributing to recovery.

In consultation with members of the REAT, the project team calculated the average decrease in risk for these six recovery actions within each desert tortoise recovery unit in California:

1. *acquisition of tortoise habitat* to facilitate recovery, focusing on particularly sensitive areas that would connect functional habitat or improve management capability of the surrounding area;
2. *installation and maintenance of fencing and signs* around tortoise conservation areas marking boundaries of particularly sensitive or heavily impacted areas to regulate authorized use and discourage unauthorized use;

3. *installation and maintenance of desert tortoise highway fencing* to eliminate tortoise road mortality, with the installation of culverts to ensure connectivity;
4. *restoration of desert tortoise habitat* in areas previously damaged by grazing, fire, or off-highway vehicles;
5. *relinquishment of grazing allotments* within desert tortoise habitat; and
6. *increase in law enforcement* dedicated to reducing threats to the tortoise within Desert Wildlife Management Areas.

The project team then compared the average estimated effectiveness for each action to determine the amount (acres or miles) of actions 2 through 6 necessary, on average, to equal the effectiveness of 100-acres of land acquisition in the West Mojave, Eastern Mojave, and Colorado Desert recovery units.

Depending on where on the landscape a specific recovery action is implemented, its effectiveness in reducing population risk to the desert tortoise will vary significantly. There are places where implementing a recovery action is very beneficial, and others where the same action would be much less beneficial. The actual relative effectiveness ratio between any two specific recovery action implementations will vary accordingly, which the team quantified using an analysis of variance. The results are summarized in Tables 3, 4, 5, and 6. For instance, in Table 2.1 for the Western Mojave Recovery Unit, it was estimated that on average it would take 10 miles of desert tortoise highway fencing to reduce the same amount of risk to the tortoise as 100 acres of land acquisition. But that ratio varied between nine miles and 17 miles, depending on where the fencing was located within the recovery unit, and always assuming suitable locations were chosen for each recovery action type.

Table 3: West Mojave Recovery Unit: Variation in Ratios of Effectiveness of Recovery Actions Compared to Land Acquisition

Recovery Action	Unit	Ratio to Land Acquisition	Variation in Ratios to Land Acquisition
Installation and maintenance of *fencing and signs around tortoise conservation areas* marking boundaries of particularly sensitive or heavily impacted areas	Miles	1	(1–3)
Installation and maintenance of *desert tortoise highway fencing* with culverts where appropriate	Miles	10	(9– 17)
Restoration of desert tortoise habitat in areas previously damaged by grazing, fire, or off-highway vehicles	Acres	395	(246– 997)
Relinquishment of grazing allotments within desert tortoise habitat	Acres	560	(510– 977)
Land acquisition	Acres	100	--

Source: Desert Tortoise SDSS

Table 4: Eastern Mojave Recovery Unit: Variation in Ratios of Effectiveness of Recovery Actions Compared to Land Acquisition

Recovery Action	Unit	Ratio to Land Acquisition	Variation in Ratios to Land Acquisition
Installation and maintenance of *fencing and signs around tortoise conservation areas* marking boundaries of particularly sensitive or heavily impacted areas	Miles	3	(1–5)
Installation and maintenance of *desert tortoise highway fencing* with culverts where appropriate	Miles	7	(3– 13)
Restoration of desert tortoise habitat in areas previously damaged by grazing, fire, or off-highway vehicles	Acres	798	(243– 2381)
Relinquishment of grazing allotments within desert tortoise habitat	Acres	662	(216– 1361)
Land acquisition	Acres	100	--

Source: Desert Tortoise SDSS

Table 5: Colorado Desert Recovery Unit: Variation in Ratios of Effectiveness of Recovery Actions Compared to Land Acquisition

Recovery Action	Unit	Ratio to Land Acquisition	Variation in Ratios to Land Acquisition
Installation and maintenance of *fencing and signs around tortoise conservation areas* marking boundaries of particularly sensitive or heavily impacted areas	Miles	3	(1–4)
Installation and maintenance of *desert tortoise highway fencing* with culverts where appropriate	Miles	2	(1– 3)
Restoration of desert tortoise habitat in areas previously damaged by grazing, fire, or off-highway vehicles	Acres	335	(116– 1029)
Relinquishment of grazing allotments within desert tortoise habitat	Acres	121	(67– 473)
Land acquisition	Acres	100	--

Source: Desert Tortoise SDSS

Table 6: Variation in Ratios of Effectiveness of Increasing Law Enforcement Compared to Land Acquisition

Recovery Unit	Area (acres)	# of 100-acre land acquisitions = 1 additional Law Enforcement Officer
West Mojave	1,271,876	124-175
Eastern Mojave	126,137	83-88
Colorado Desert	1,641,113	142-194

Source: Desert Tortoise SDSS

In general, the project partners would recommend that managers locate specific projects in areas with highest possible effectiveness, and costs permitting, move to other recovery actions once the most effective areas for a particular recovery action have been exhausted.

2.3 Site-Specific Recovery Action Design and Tracking

The second objective to improving system calculations for the population effects of recovery actions involved adding new recovery action data, as well as making changes to system tools, architecture, and workflows. These activities provide a means for users to define site-specific recovery actions for inclusion in mitigation packages, and to calculate the resulting reduction in risk to the tortoise population.

2.3.1 Recovery Action Database

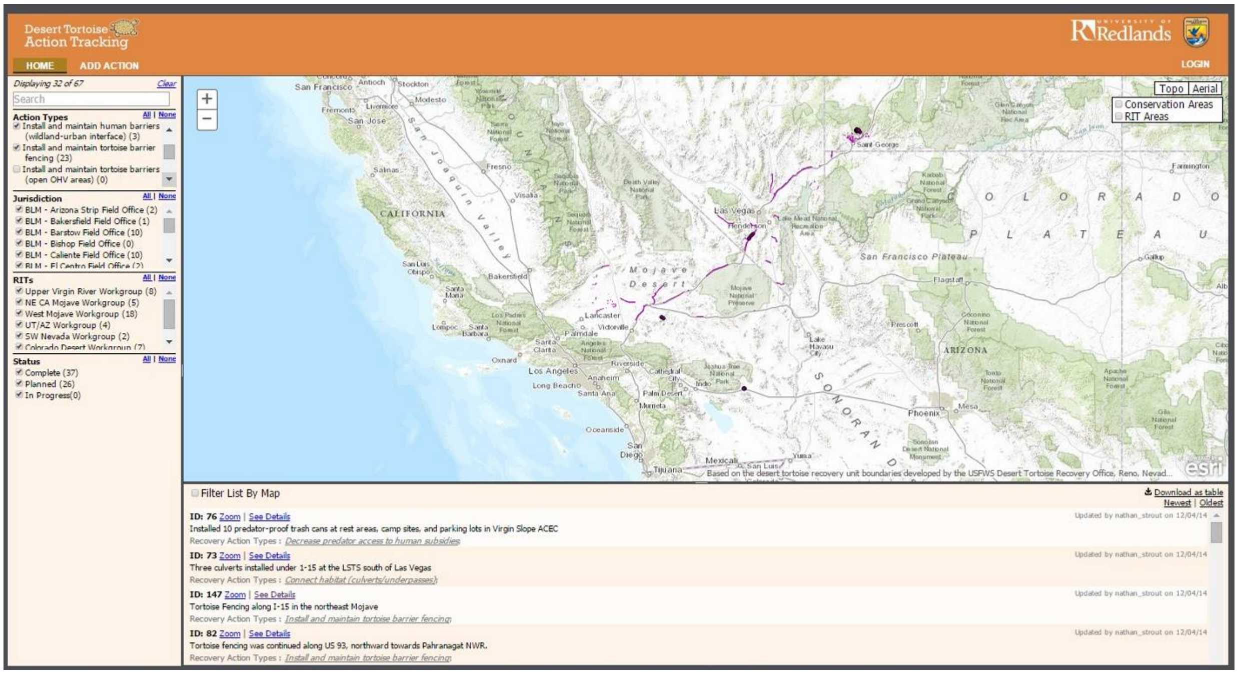
Building on work funded separately by USFWS, the project team loaded 800+ recovery actions into the SDSS database, gathered from scientists and managers involved in the Recovery Implementation Team (RIT) processes of 2012. The Recovery Action Plan for the California Desert RIT can be found here: http://www.fws.gov/nevada/desert_tortoise/documents/recovery_plan/20140508.ca.mojaverit_recoveryactionplan_v1.pdf.

These expert-defined recovery actions provide useful information about priority management actions for desert tortoise recovery. It is important to note that while a subset of recovery actions may be associated with a specific location on the ground (e.g., tortoise fencing), others apply to the entire range or are non-geographic in nature (e.g., environmental education).

2.3.2 Recovery Action Tracking Tool

As part of this project, the team integrated into the SDSS an online application for range-wide recovery action tracking and monitoring, developed with additional support from USFWS. In the *Recovery Action Tracking* dashboard, users can define recovery actions by entering key properties and then sketching, uploading, or selecting locations to geographically reference the action (Figure 12). This information can be updated by users throughout the action's lifespan from the planning stages to completion. Designed recovery actions are stored in the Recovery Action database and available for use by other land managers and solar project proponents when defining mitigation plans. These designed recovery actions can be queried, displayed, and reported on in the interactive mapping interface.

Figure 12: Recovery Action Tracking Tool



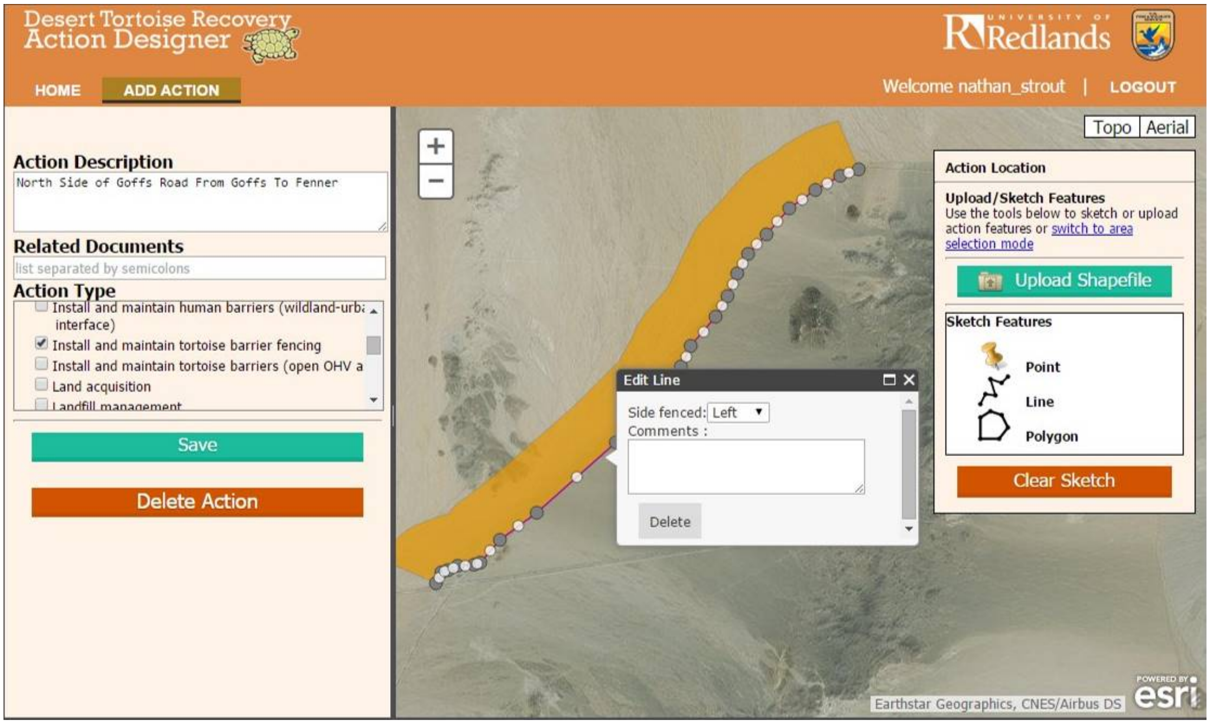
Recovery Action Tracking tool interface, where users can display and review the available recovery actions for inclusion in mitigation packages. From this home page users can also access the Recovery Action Designer tool (Figure 2.5), via the Add Action tab, which provides editing tools to define new recovery actions.

Source: Desert Tortoise Recovery Portal

2.3.3 Recovery Action Designer

The *Recovery Action Designer* developed under this project extends the functionality of the Recovery Action Tracking tool, by leveraging the SDS engine to estimate the risk reduction of a sketched or uploaded action footprint. For the Desert Tortoise SDSS to *quantitatively* calculate how a specific management action reduces risk to the population, the user must provide: (a) the *intensity* of that recovery action, (b) a *specific* location and footprint (a site-specific recovery action), and (c) secondary information that may be required to execute the risk reduction calculation. Once these site-specific actions are designed, the system engine can then calculate the risk reduction the action would produce and make the action available for inclusion in mitigation packages (Figure 13).

Figure 13: Recovery Action Designer Tool



The Add Action tab in the Recovery Action Tracking tool opens the Recovery Action Designer, which allows users to review planned, in progress and completed actions, and describe new recovery actions to be implemented. Users can designate related action plan elements and a maintenance cycle for the action, sketch or edit features or upload a shapefile of recovery action footprints.

Source: Desert Tortoise Recovery Portal

The Recovery Action Designer allows users to quantitatively define the *intensity* of a recovery action and its specific geographic *location* (footprint) for use in system mitigation calculations. As noted above, not all recovery actions lend themselves to a spatially-explicit implementation. Therefore, the Recovery Action Designer currently operates on the subset of six recovery actions prioritized by the REAT and described in Section 2.2 above, for which the user can fully designate both the intensity and spatial footprint for implementing that action as part of a specific mitigation package associated with a specific project.

Both the Recovery Action Tracking Tool and the Designer share the same design engine and store their spatially-explicit designs in a common database. The database is accessed by another system component, the Solar Project Impact and Mitigation Calculator, which computes the change in risk to the tortoise population resulting from implementation of a site-specific recovery action. These tools are all part of the revised online Desert Tortoise Recovery Portal as described in Chapter 6. Integrating these tools in a common architecture allows users to: (1) track a mitigation action from its design phase to implementation, and (2) once implemented, compare actual effectiveness to estimated effectiveness to reevaluate the modeled assumptions in support of adaptive management.

The recovery action database and online tools can be accessed through the portal, or directly from: http://www.spatial.redlands.edu/dtro/ActionTracking.

2.4 Projecting Increase in Risk Under Climate Change Scenarios

An initial objective of this project was to integrate new habitat suitability model outputs from the USGS predicting future habitat potential for desert tortoise under multiple climate projections. While the project partners were unable to secure these data, in the future this will permit a re-calculation of the probability of presence layer, and in turn, refined calculations of risk to the desert tortoise under climate change. The project partners expect that some recovery actions will remain effective across several climate scenarios, while others will only be effective under a single scenario. Those recovery actions that are projected to be effective under multiple scenarios should be prioritized.

CHAPTER 3: Model Improvements and Population Fragmentation

Research completed under the first Energy Commission grant revealed that population fragmentation can be an important impact of utility-scale solar energy development. The original model for population fragmentation in the Desert Tortoise SDSS took into account only the probability of presence for the tortoise in the area removed due to habitat loss, and whether the area fell within a "linkage:" defined as a least-cost travel corridor of habitat, often degraded, which connected TCAs (Averill-Murray et al. 2013). This original approach did not take into account that fragmentation causes population-level effects between and among patches of tortoises. In addition, though the conceptual model included the two recovery actions of "Connect habitat (culverts/underpasses)," which acts to reduce the contributions of both railroads and paved roads to the stress of fragmentation, and "Habitat restoration," the above simple model provided no spatial computation to estimate the effect of these recovery actions in the system. The exception is the case where habitat restoration meant a fenced off area was made accessible again. Developing a better sub-model for population fragmentation was a core objective for this second project.

This chapter explores several alternative approaches to estimating fragmentation effects on tortoise populations, and how these may be integrated in the SDSS impact calculations. The team's criteria (conceptual and computational) for an acceptable new model were that it:

1. is based on a conceptually more faithful model of how a local tortoise population responds to degradation of its local habitat (at least compared to the previous model);
2. connects local habitat fragmentation measures to range wide population fragmentation measures;
3. computationally demonstrates sensitivity to changes on the scale of interest; and
4. provides local and range wide measures that are computational in (near) real time.

While the desert tortoise does not lend itself to many traditional fragmentation models, meta-population theory can capture connectivity aspects important for the tortoise through the metric of *Population Capacity*. The project partners tested this new metric, and a traditional *probability of connection* metric, using three scenarios in the Ivanpah Valley study area. The *Population Capacity* was a good metric for population fragmentation within the Ivanpah Valley, satisfying the first three criteria, but failing, at least on the computer systems available to the team, on the fourth, as it presented computational challenges for scaling up to a range-wide measure. Subsequently, the project team developed an alternate *rescuability (resilience)* metric that quantifies the likelihood of an area being "rescued" by immigrants from neighboring areas, that is fast to calculate locally and is readily incorporated into the range-wide calculations of risk to population. In the process the project partners created a new spatial layer, *altered habitat potential* that models anthropogenic changes to the landscape as *resistance* by altering habitat potential values where these threats occur.

3.1 Importance of Connectivity for Desert Tortoise Recovery

The historic distribution of Mojave desert tortoises was relatively continuous across the range, broken only by major topographic barriers, such as Death Valley, California, and the Spring Mountains, Nevada (Germano et al. 1994; Nussear et al. 2009). Although desert tortoises do not immigrate long distances, modest dispersal and connectivity of neighboring home ranges fostered high levels of gene flow and a population structure characterized by isolation-by-distance (Murphy et al. 2007; Hagerty and Tracy 2010; Hagerty et al. 2011). Human disturbances that fragment habitat have resulted in small genetic differences even across relatively short distances: pairs of tortoises from opposite sides of a road exhibit significantly greater genetic differentiation than pairs from the same side of a road (Latch et al. 2011). This validates concerns about population fragmentation resulting from larger scale habitat loss, as may result from utility-scale energy developments. Maintaining functional, interconnected landscapes is necessary to conserve historic genetic gradation, thereby preventing habitat specialization and genetic divergence between populations. Similarly, large, interconnected landscapes may be necessary to allow for natural range shifts in response to climate change (Krosby et al. 2010; National Fish, Wildlife, and Plants Climate Adaptation Partnership 2012).

Large expanses of habitat are necessary to allow local clusters of tortoises that experience sufficient recruitment and dispersal under favorable environmental conditions within their habitat patch to repopulate or "rescue" suitable habitat patches with no or few tortoises that resulted from poor environmental conditions, low recruitment, and high mortality (Germano and Joyner 1988; Morafka 1994; Tracy et al. 2004). Demographic connectivity (immigration/emigration between habitat patches) not only promotes population stability within individual habitat patches, but also across metapopulations (Lowe and Allendorf 2010). However, rescue of unoccupied habitat patches may not occur or may be delayed if dispersal of desert tortoises is density-dependent (that is, if few tortoises disperse from small or declining populations, these populations will be ineffective in rescuing adjacent, unoccupied patches; Adler and Nuernberger 1994).

3.2 Modeling Desert Tortoise Population Fragmentation

The original approach in the Desert Tortoise SDSS modeled the contribution to risk to desert tortoise recovery from population fragmentation as only the area removed due to habitat loss. This did not take into account that fragmentation causes population-level effects between and among patches of tortoises. The new approach has been to implement one of the emerging connectivity metrics that handles just such aspects of population fragmentation, and then integrate that metric into the SDSS. The objective is to replace the original area-based additive submodel for population fragmentation with one that explicitly handles spatial, population-level impacts to connectivity.

Interestingly, the desert tortoise does not lend itself to many traditional fragmentation models given its modest dispersal and connections of neighboring home ranges over a relatively continuous distribution, as opposed to well-delineated habitat patches separated by expanses across which migration occurs. However, metapopulation theory (Hanski 1991; Hanski and Gyllenberg 1997; Hanski and Ovaskainen 2000), in which subpopulations in an area naturally become extinct only to be recolonized again by neighboring occupied patches, does capture connectivity aspects important for the tortoise. The project partners designed an approach that uses metapopulation theory (Hanski 1991; Hanski and Gyllenberg 1997; Hanski and Ovaskainen 2000) with the individual territory model (Noon and McKelvey 1996) to characterize the effects of desert tortoise population fragmentation where historically continuous interconnected habitat patches become disconnected. For comparison, the project team also estimated the well-known *probability of connection* index (PC Index; Saura and Pascual-Hortal, 2007) to characterize connectivity for dispersed populations.

To represent tortoise movement and habitat quality that both the above approaches require, the project team developed an *altered habitat potential* (AHP) surface across the entire range. The value of the AHP in a localized area indicates the quality of habitat in that area, while the multiplicative inverse of its value quantifies *resistance* to tortoise movement across that area.

3.3 Quantifying *Resistance* to Desert Tortoise Movement

As described above, successful movement of animals across the landscape may fulfill a number of biological processes, including foraging, mating, migration, dispersal and gene flow. Habitat fragmentation results in decreased *connectivity*, which is the degree to which factors in the landscape facilitate or impede individual movement among resource or habitat patches (Taylor et al. 1993).

Resistance to movement can provide a quantitative estimate of how environmental factors affect animal movement. Resistance represents the willingness of an organism to cross a particular environment, the physiological cost, or the reduction in survival for the organism moving through that environment, or a combination of these factors. Resistance is often estimated by parameterizing environmental variables across continuum representing the 'resistance' or 'cost' to movement, where a low resistance denotes ease of movement and a high resistance denotes restricted movement or an absolute barrier (Zeller et al. 2012).

Resistance is affected by natural topographic features (such as mountains) as well as natural habitat quality features (such as vegetation or number of shelter sites); resistance is also affected by anthropogenic changes to the landscape (such as urbanization) (Heinem and Merriam 1990). The project team therefore used the USGS Habitat Potential map (USGS 2009) as the base for a *resistance* layer, altering the habitat potential values where anthropogenic threats occur on the landscape in a way similar to how habitat potential is used in the *probability of presence* layer. The *probability of presence* layer only considered complete habitat loss, so that areas covered by impervious surfaces are set to zero habitat potential. However, in the resistance surface the project partners are also interested in more subtle anthropogenic changes that may affect movement but not do result in complete habitat loss.

Habitat suitability values generated for each pixel across the landscape can be converted directly into metrics of resistance to movement (Spear et al. 2010). For the Mojave desert tortoise, the project team used habitat potential values from the USGS (Nussear et al.

2009) to capture natural topographic and habitat quality resistances. The team modeled anthropogenic changes to the landscape as resistance by *altering habitat potential* where these threats occur. The tables below describe habitat potential values for threats that may destroy habitat (Table 7) or degrade habitat (Table 8) and result in habitat fragmentation. Where urbanization (completely developed) occurs resistance is 1.0 and habitat potential is zero; where other threats such as unpaved roads occur and only slightly increase resistance, then habitat potential is only slightly reduced. The *resistance* layer is calculated as 1.0 minus the AHP layer (Spear et al. 2010).

To develop the AHP surface, the project partners adjusted the USGS habitat potential surface using NLCD 2006 Landcover data by: (1) removing impervious surface areas, and (2) using consensus-based expert assessment by the USFWS DTRO to determine by how much defined anthropogenic threats reduce habitat potential. This created the AHP layer, which was cross-checked against satellite imagery.

Table 7: Altered Habitat Potential (AHP) Values Applied to NLCD (2006) Landcover Classes and Threats that Destroy Habitat

Landcover Classes and Threats that Destroy Habitat	Habitat Potential (reduced to)
NLCD Class 22: Developed, Low Intensity - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.	0
NLCD Class 23: Developed, Medium Intensity – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.	0
NLCD Class 81: Pasture/Hay – areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.	0
NLCD Class 82: Cultivated Crops – areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.	0
Major Paved Roads (CARTO field = 1 & 2)	0
Mineral Development	0
Solar Energy Development	0
Geothermal Energy Development	0
Aqueducts	0
Railroads	0
RA: Tortoise Fencing	0

Source: USFWS DTRO

Table 8: Altered Habitat Potential (AHP) Values Applied to NLCD (2006) Landcover Classes and Threats that Degrade Habitat

Landcover Classes and Threats that Degrade Habitat	Habitat Potential (reduced to/by)
NLCD Class 21: Developed, Open Space - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes. (imperviousness < 20%)	Reduced to 0.2
Minor Paved Roads (CARTO field = 3 – 8)	Reduced to 0.2
All remaining NLCD impervious surfaces not captured in Developed Classes below appear to be unpaved linear features, thus are given the same habitat potential reduction value as unpaved roads.	Reduced to 0.4
Unpaved Roads and Routes	Reduced to 0.4
Open OHV Areas	Reduced by 50%
Grazing	Reduced by 33%
Military Operations	Reduced by 33%
Historical Fire (past 15 years)	Reduced by 33%
Wind Energy Development	Reduced by 10%

Source: USFWS DTRO

When multiple threats occur at the same place, the AHP is calculated by taking the lowest values generated by the above tables. Note that where habitat potential has a null value at a cell (typically on lake surfaces) the altered habitat potential is set equal to zero.

3.4 Dynamic Diffusion Model: FRAGGLE

To develop a quantitative analysis that would exhibit dynamics of patch rescue and take into account resistance to movement across a landscape, the project partners investigated using the FRAGGLE diffusion model.

FRAGGLE is a patch-based, dynamic diffusion model for population fragmentation. The FRAGGLE tool simulates subpopulation exchange scenarios under differing land-use configurations to generate connectivity indices among populations (BenDor et al. 2012). The program was originally tested using the gopher tortoise (*Gopherus polyphemus*), a threatened species whose southeastern U.S. distribution has diminished significantly within its native range due to agricultural and urban development. FRAGGLE simulates tortoise dispersal (due to overcrowding in a home range) with a cellular automata approach: recording, for each simulation step (year), the genetic mixing of a sub population (its genetic lineage). FRAGGLE produces an overall genetic mixing index at the end of a simulation run, which can be used to compare how different development scenarios affect tortoise genetic mixing. This was a candidate quantitative metric that could potentially be integrated into the Desert Tortoise SDSS.

The gopher tortoise and Mojave desert tortoise have similar life history and movement traits that operate on similar spatial and temporal scales. The project team piloted the use of FRAGGLE for simulating the patch-rescue potential among different desert tortoise habitat patches, in order to assess the effects of habitat fragmentation on functional connectivity. The study area was in the Ivanpah Valley, including the Ivanpah to Piute - El Dorado Linkage (Averill-Murray et al. 2013) and surrounding area.

3.4.1 Approach

Using FRAGGLE required three steps: data preparation; habitat patch delineation, and a simulation run. The input map layers required by FRAGGLE were:

- *Habitat*: the desert tortoise habitat area
- *Dispersal attractiveness*: attractiveness for supporting tortoise dispersal
- *Mortality probability*: death rate of tortoises during dispersal process
- *Subpopulation*: tortoise subpopulation areas

The project team modified the approach used for preparing input data to FRAGGLE (BenDor et al. 2012) due to several considerations.

- Because FRAGGLE was designed for gopher tortoises, some of the parameters used in input data preparation, such as home range size, needed to be adapted for Mojave desert tortoises.
- The project partners had a different purpose for this population fragmentation exercise than the developers of FRAGGLE had. Instead of simulating the subpopulation mixing potential over the years, the partners wanted to simulate the *patch-rescue potential* among different tortoise habitat patches, especially in identified priority corridors, regardless of whether the patches belong to the same subpopulation or not. The subpopulation mixing potential calculated by the FRAGGLE model would thus become a proxy for the potential of patch rescue.
- The project team used different data sources and, sometimes, different processes in preparing the input data, which is an improvement since this project's data sources are based on more sophisticated modeling.

All the input data layers were rasters 500 m in resolution (approximating the size of a desert tortoise home range) to be compatible with FRAGGLE's calculation algorithm, which uses a cell size that is close to the species' home range size. Table 9 summarizes the derived input layers used in this exercise.

Table 9: Derived Input Layers Used in FRAGGLE for Mojave Desert Tortoise

Input Layer (and Input name from BenDor)	Description & Data Source	Derivation Process Summary and Output
Habitat (Habitat)	Tortoise habitat area, with core and edge area distinction. Edges are 1 home range size wide (500 m). Data source: Movement Attractiveness layer, derived from AHP layer as a proxy	The project team varied from the BenDor et al. (2012) derivation process to allow variation in the habitat suitability values in the habitat area. Using Movement Attractiveness layer, select cells with suitability value of 0.4 as habitat that were also part of the habitat patch layer (see below). Create habitat core and edge layers, then combine into an output raster where core habitat value = 2, edge habitat = 1, and non-habitat = 0.
Movement Attractiveness (Dispersal Attractiveness)	Attractiveness for supporting tortoise dispersal. Data source: AHP layer, which results from resistance calculation described in Section 3.3.	Aggregate AHP layer of 100 m cells to 500 m cells using cell value averaging method. Aggregate another 500 m raster with only 0 value cells (e.g., roads). Combine aggregation layers to create an output raster with values 0 - 1.0, with 1.0 being the highest movement attractiveness value.
Mortality Risk (Mortality Probability)	Probability of tortoises being killed while moving through an area. Source data: total tortoise mortality risk layer, as a proxy. Ideally, separate adult and juvenile mortality risk layers, based only on threats causing direct mortality, would be used.	Aggregate total tortoise mortality risk layer to 500 m cell size, and rescale the value between 0 - 1.0, where 1.0 is the highest mortality risk value.
Habitat patches (Subpopulation)	Defined patches of tortoise habitat. In BenDor et al. (2012), the area of suitable habitat land cover where the dispersal potential is 1.0. Data source: AHP layer as a proxy	The methods in this project varied from BenDor et al. (2012) in using *PatchMorph* to delineate patch areas (see Section 3.4.1.2 below) Starting with the 100m AHP layer, use PatchMorph to derive habitat patches. Aggregate the output and eliminate (a) 0 valued areas (e.g., roads), and (b) patches below the minimum patch size threshold. Use this habitat patch layer to “cookie cut” the habitat core-edge data layer as described above.

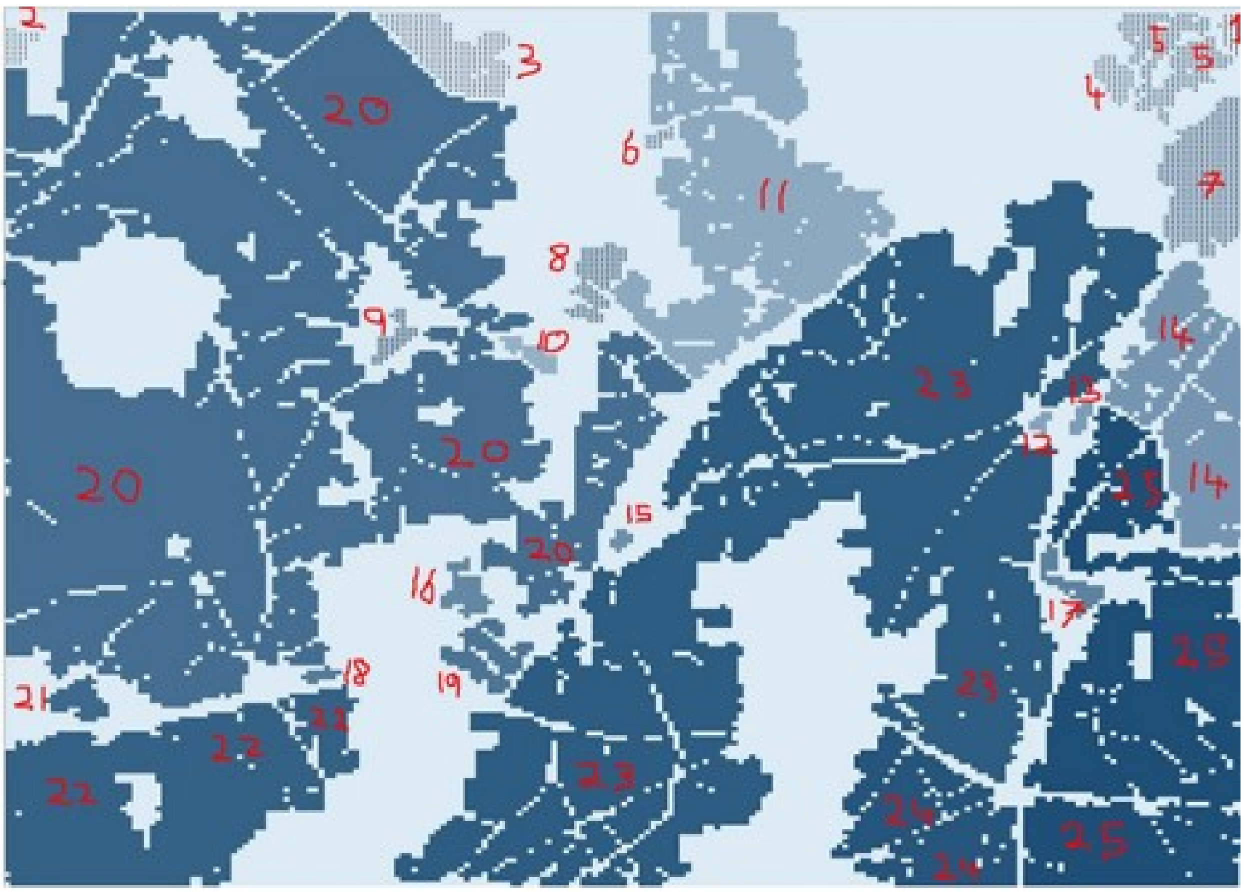
Source: Desert Tortoise SDSS

3.4.1.1 Habitat Patch Delineation

FRAGGLE simulates the patch-rescue potential among different tortoise habitat patches, regardless whether the patches belong to the same sub population or not. This requires delineating patch boundaries. Instead of the manual process used by BenDor et al. (2012), the project team explored several tools for automating this process that would create patches of contiguous area, starting from high habitat potential value cells and "growing" outwards. The team also had to consider minimum patch size.

PatchMorph for ArcGIS 10, a Python tool, was used to delineate patches across a range of spatial scales based on three organism-specific thresholds: (1) land cover density threshold (using desert tortoise habitat suitability threshold), (2) habitat gap maximum thickness (gap threshold for distance between patches that a desert tortoise could successfully cross), and (3) habitat patch minimum thickness (spur threshold). The AHP layer of 100m resolution was used as input to PatchMorph and defined the threshold for habitat suitability (40%), maximum gap threshold (2 cells, e.g., 200 m), and maximum spur width or minimum patch width (500 m). The result of the threshold choices and parameter settings in PatchMorph was the creation of 25 patches that varied from the smallest (patches 1, 2) to the largest (20, 23; Figure 13).

Figure 13: 25 Habitat Patches Created Using PatchMorph



Areas of low AHP (mainly mountains and human development) make up the empty intraspatial zones.
Source: Desert Tortoise SDSS

3.4.1.2 Simulation Runs

For the simulations in the Ivanpah study area, the project partners modified the code of FRAGGLE to apply the desert tortoise input parameters, since these are hard coded and cannot be specified in the user interface. Table 10 summarizes the input parameters for desert tortoise (DT Values), and those for the gopher tortoise in comparison (GT Value), for the FRAGGLE simulation runs. The DT Values are based on the stable population studied in Turner et al. (1987).

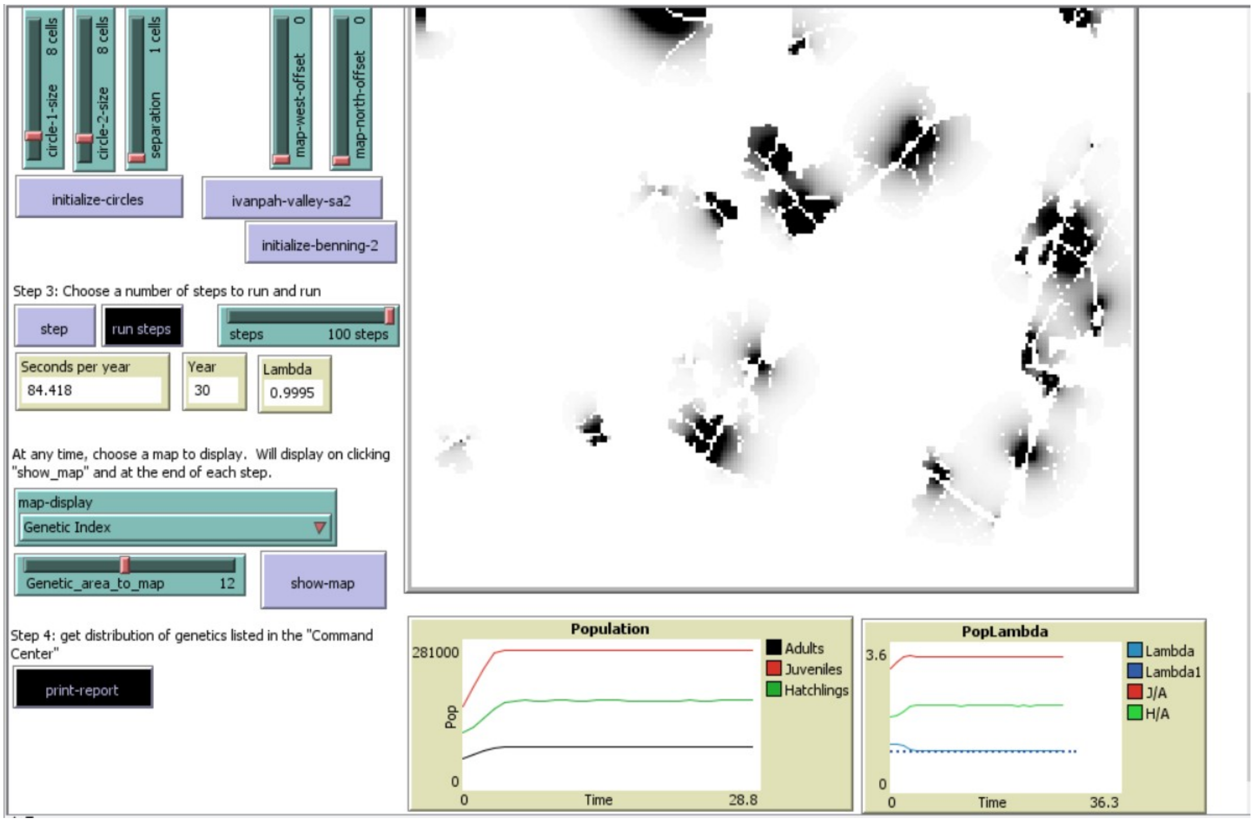
Table 10: FRAGGLE Input Parameter Values for Desert Tortoise (DT) Compared to Gopher Tortoise (GT)

Input Parameter	DT Values	GT Value
Min number of hatchlings initialized in core areas	0	0
Max number of hatchlings initialized in core areas	0	0
Percent of hatchlings in edges that are lost to predators	0.15	0.81
Percent of hatchlings in core that are lost to predators	0.15	0.81
Percent of hatchlings everywhere else that are lost to predators	1	1
Min number of juveniles initialized in core areas	0	5
Max number of juveniles initialized in core areas	17	10
Percent of juveniles die each year in edges	0.18	0.2
Percent of juveniles die each year in core	0.18	0.1
Percent of juveniles killed by predators each year outside patch	1	1
Percent of juveniles that move each year even if not overpopulated	0.02-0.05	0.05
Years as juvenile	14	20
Min number of adults initialized in core areas	0	1
Max number of adults initialized in core areas	4	3
Min number of hatchlings per adult per year	0	4
Max number of hatchlings per adult per year	3.29	8
Percent of adults lost each year to predation in the edge habitat	0.05	0.03
Percent of adults lost each year to predation in the core habitat	0.05	0.03
Percent of adults lost each year to hunting	0	0
Percentage of adults that move each year even if not overpopulated	0.05-0.1	0.05
Max number of adults per home range	2-4	3

Input Parameter	DT Values	GT Value
Max number of juveniles per home range	13	12
Max adult dispersal distance per year	1000m-10000m	2000 m
Max juvenile dispersal distance per year	500m-2000m	1000 m

Source: Turner et al. (1987) for DT Values; BenDor et al. (2012) for GT Values

Figure 14: Initial FRAGGLE Model Simulation Run Results (30 Years of Diffusion)



The FRAGGLE interface showing results after simulation of 30 years of diffusion. Parameter values were provided by the DTRO, as displayed in the Table 3.4.

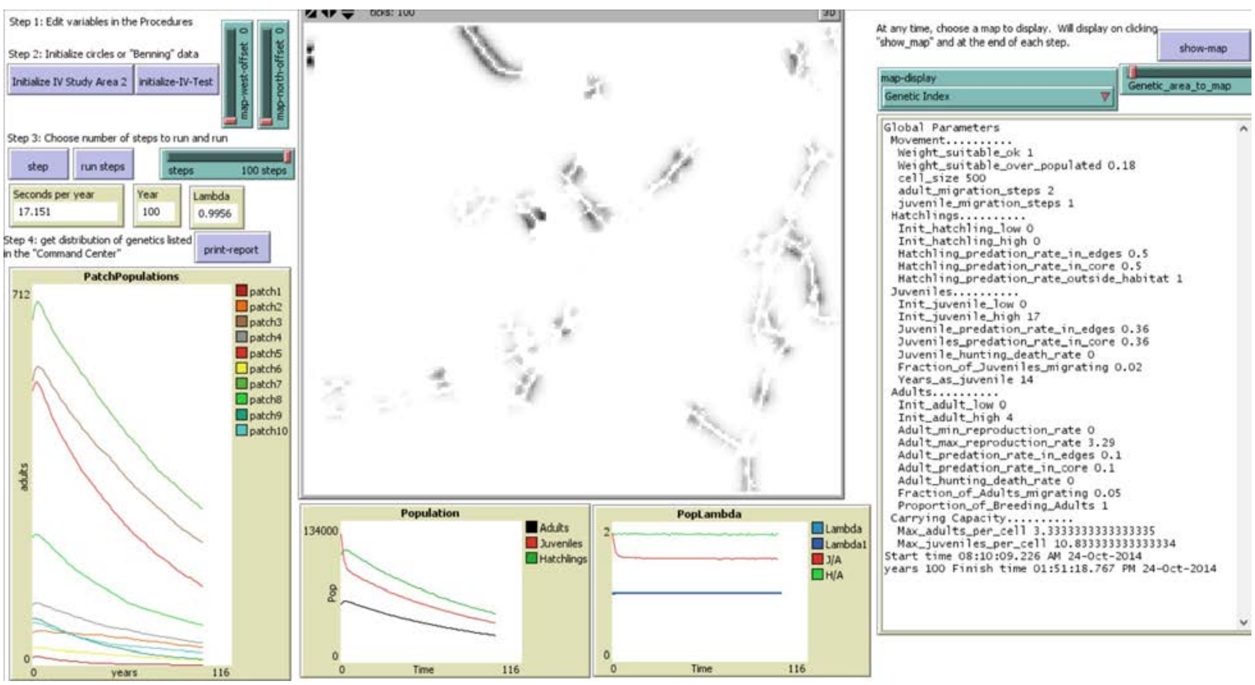
Source: Desert Tortoise SDSS; BenDor et al. (2012).

In the initial model run, FRAGGLE performed 30 steps in the run, simulating 30 years of "patch mixing" (Figure 14). The run was done based on the current desert tortoise habitat condition. The parameter values were those provided by the DTRO in Table 3.4, which were based on values from Turner et al, 1987, with some adaptation. Where a range was provided by the DTRO, the blue "optimistic" values were used. The "map" panel in the FRAGGLE windows below shows the degree of patch mixing, with darker colors indicating areas of higher degree of patch mixing. In the population graph, the juvenile population stabilized when the number of juveniles hit the specified carrying capacity of 13 juveniles per home range. The adult and hatchlings curve stabilized soon after. While this may occur for a stable population (such as in

Turner et al. 1987, and used as the basis for most parameters in this exercise) it is unlikely to hold for the current desert tortoise population that is in decline (USFWS 2014).

Following the initial run, the project team continued the simulation through 100 years of diffusion and made changes to the FRAGGLE interface in order to (a) better monitor changes in the adult populations for a number of important habitat patches; and (b) visibly display the parametric values being used in the model runs (Figure 15).

Figure 15: Improved FRAGGLE Model Simulation Run Results



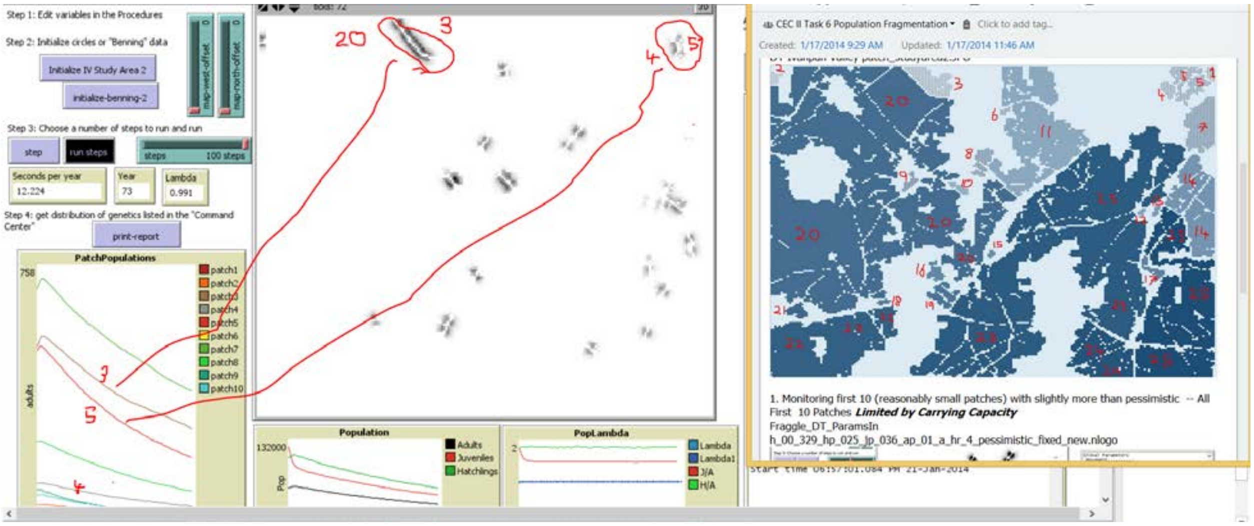
The FRAGGLE interface showing results after simulation of 100 years of diffusion. The project partners extended the interface to track changes in the adult populations across a number of key patches (left lower chart) and made parameter values explicit (right hand panel).

Source: Desert Tortoise SDSS; BenDor et al. (2012).

3.4.2 Discussion

In pursuing this exercise, the project partners hoped that FRAGGLE would provide a quantitative analysis that exhibits dynamics of patch rescue and takes into account resistance to movement across a landscape. It was hoped this analysis also might reveal "thresholds of collapse" based on habitat fragmentation: the idea that if fragmentation reaches a certain point, then the population will collapse.

Figure 16: FRAGGLE Genetic Index



The “Genetic index” in FRAGGLE shows where adults from other patches show up within a patch. Generally, they occur only at the edges of the larger patches.

Source: Desert Tortoise SDSS; BenDor et al. (2012).

The simulations revealed that due to the size of the larger patches and the relatively small movement distance of the tortoises, in the FRAGGLE diffusion model mixing of patch populations only occurred at the fringes of the larger patches, even over simulations of 100 years (Figures 15 and 16). Also, regardless of patch sizes and neighbors, the trajectory of the adult populations quickly falls into lockstep across patches, resulting in a monotonic decrease (or increase with extreme values). As such, the simulations failed to reflect any form of rescue behavior, between patches or within patches, that has been observed (Germano and Joyner 1988)) and which the high spatial variation in threats across the range would have led the project partners to expect. Finally, there is nothing in the desert tortoise research literature that would support the patches as derived using PatchMorph. In all, the FRAGGLE results showed very simple, non-spatial behavior that called into question the use of a complex diffusion approach.

Multiple efforts to refine patch definition for use in FRAGGLE did not yield substantial improvements. For example, FRAGGLE assumes that tortoises cannot live in the interstitial spaces between habitat patches: all juveniles and adults in the interpatch areas are killed at the end of each year. For desert tortoises, there is evidence that they can and do live in these spaces and might, depending on the situation, survive long enough to reach a new habitat patch. The project team removed the code that killed of all adults who remained in the inter-patches spaces at the end of each year in the simulation. The team also employed the AHP layer to provide for varying movement resistance surfaces within the patches themselves. None of these changes yielded substantial differences in the FRAGGLE outputs.

Finally, FRAGGLE was computationally intense, and very dependent on the demographic and habitat parameters used, some of which are not well established in the literature. It was clear that any attempt to create smaller patch sizes or scale the analysis from the Ivanpah Valley study area to the full range would be computationally prohibitive. Eventually and in consultation with FWS DTRO, the project partners determined that FRAGGLE was not a suitable model for understanding desert tortoise population fragmentation.

What the team learned from the experiments with FRAGGLE was that introducing movement into the otherwise static interplay of habitat fragmentation and the life characteristics of the tortoise lead quickly to outcomes of either collapse or asymptotic growth; with the long term outcome very sensitive to those poorly known life characteristics. What was needed was a representation of tortoise population dynamics that could incorporate the effects of movement and predict the end state of the population, without requiring simulation of individual behavior or diffusion. The team concluded explorations in FRAGGLE and pursued the metapopulation approach described below.

3.5 Metapopulation-Based Approaches to Population Fragmentation

Following the experiments with FRAGGLE, the project partners searched the literature for other conceptual frameworks that supported patch rescue, allowed for continuous occupation across the range and incorporated spatial characteristics of the landscape in a more general fashion that does not require modeling of individuals or population diffusion.

Two approaches in metapopulation theory that met the necessary criteria: (a) a general connectivity metric known as *probability of connection*; and (b) a framework for estimating the impact of connectivity on population dynamics, from which the project partners developed a hybrid metric of *Population Capacity*. The team also developed a simple, computationally fast metric called *rescuability* (*resilience)*.

These metrics were tested for three solar energy development scenarios in the Ivanpah Valley study area upon the advice of the FWS DTRO: (1) Pre-Columbian scenario, (2) Post-Brightsource Ivanpah Solar Energy Generating System (ISEGS) – referred to as the (2014) Baseline scenario, and (3) a scenario with ISEGS plus projected First Solar Stateline and Silver State footprints. (By 2015 construction has started on both sites but with different footprints.) See Figure 3.11 for the location of the three solar energy projects (one existing, two proposed) within the Ivanpah Valley study area.

3.5.1 *Probability of Connection Index*

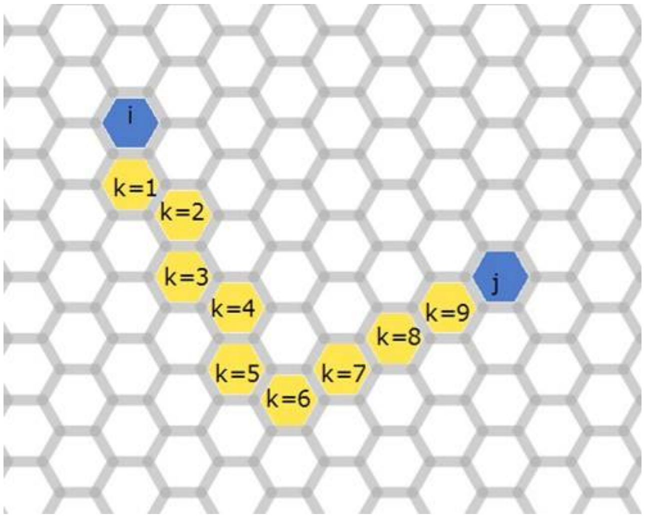
Saura and Pascual-Hortal (2007) described a general metric for fragmentation of habitat patches, the *probability of connection index (PC Index):*

$$\boldsymbol{PC = \sum_i \sum_j^n (A_i * A_j * pp^*_{ij}) / A_R^2} \qquad \textbf{Eq. 1}$$

Where A_i is a measure of the value of the patch *i*; *ppij* is the probability of the most likely path between *i* and *j, n* is the total number of patches and A_R is the area of the range.

One characterization of the probability of the most likely path is a distance-decay, where the total distance is along the pathways between patches and across the patches k themselves (Figure 17). The most likely path is the path with the highest value of the distance-decay. L is a characteristic travel distance of individuals of the specific species. In the case of the desert tortoise, the team chose L to be the lifetime dispersal distance for adult female tortoises.

Figure 17: Probability of the Most Likely Path as a Distance Decay



The probability of traversing a path from patch I to patch j. The most likely path has the highest value of the distance decay.

Source: Desert Tortoise SDSS

Probability of traversing path from patch i to patch j:

$$\boldsymbol{P}_{\boldsymbol{ij;path}} = \boldsymbol{e}^{-((\sum_{k=0}^{n} \boldsymbol{D}_{\boldsymbol{k}})/\boldsymbol{L})}$$

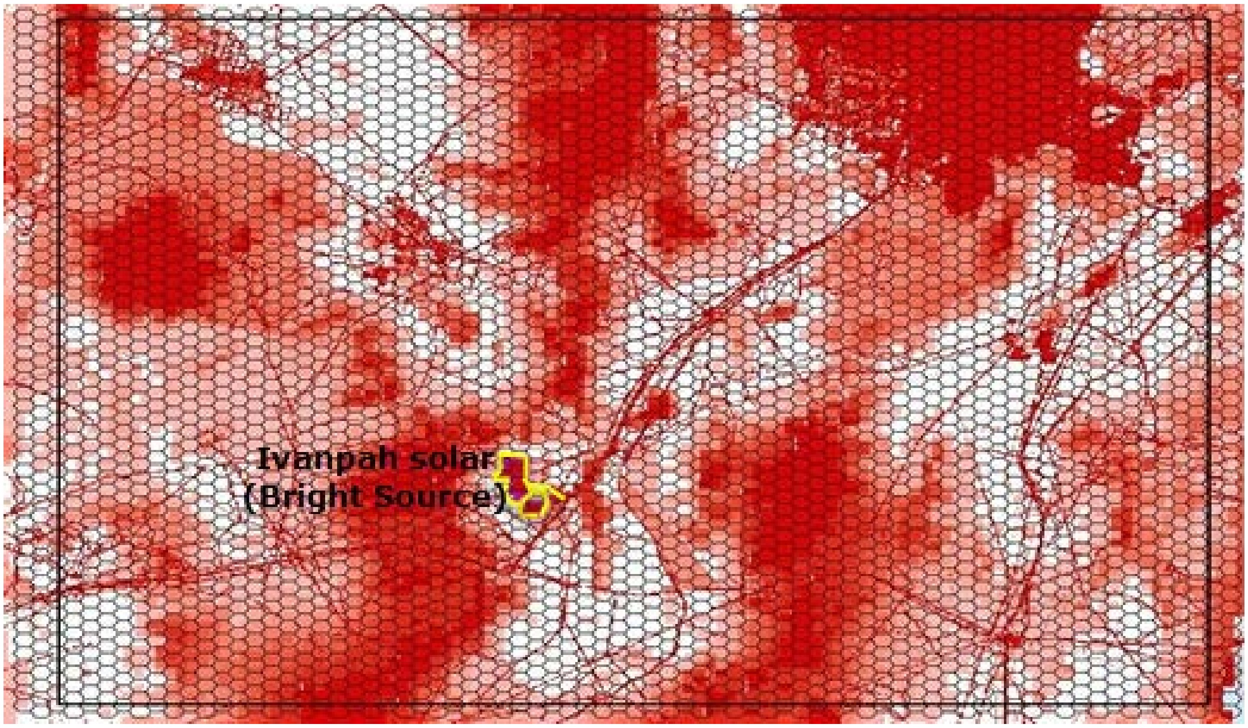
and the most probable path is

$$pp^{*}_{ij} = maximum(\boldsymbol{P}_{\boldsymbol{ij;path}})$$

Because fragmentation represents the decrease in the degree to which a landscape facilitates individual movement among resources or habitat patches, the AHP layer was used as the starting point for this patch analysis. For simplicity, the project team defined each patch as equal to one tortoise home range at ~30 ha each. The next step created a hexagonal surface (tiling) in which each hexagon represented 30 ha and overlaid this with the AHP layer to represent non-overlapping desert tortoise home ranges (Figure 18). This allowed the team to:

- Use $1/\boldsymbol{AHP}_{\boldsymbol{k}}$ as proxy for resistance to movement across territory k; and
- Use $\boldsymbol{AHP}_{\boldsymbol{k}}$ as a proxy for habitat quality on territory k.

Figure 18: Hexagonal Surface With Area-Weighted AHP



Hexagonal tiling of study area showing area-weighted AHP across each hexagon, but with a threshold where the entire hexagon was considered impassable (AHP=0) if more than 30% of its area was impervious. The project team used this threshold because 30% is roughly the area a 4 lane highway cutting across the 30 hectare hexagon would occupy. Darker red areas have lower AHP values (e.g., mountains); ISEGS project footprint provided as a reference point in dark pink.

Source: Desert Tortoise SDSS

From this the *effective distance (ED)* from territory *i* to *j* can be calculated as:

$$ED_{ij} = \sum_{k=1}^{m} D_l / AHP_k \qquad Eq.2$$

where the path traverses m territories and D_l is the Euclidean distance across territory l. Essentially the Euclidian distance across each hexagon is divided by the AHP, which takes values between 0 and 1, where 1 is perfect habitat for the desert tortoise.

3.5.2 *Population Capacity*

The second metric explored in this research combines metapopulation and individual territory models for population dynamics. The principal eigenvalue of the connection matrix, which the project partners call the *Population Capacity*, is the metric that emerges from the analysis.

3.5.2.1 The Spatially Explicit Metapopulation Model

In a series of papers between 1991 and 2000, with various collaborators, Hanski developed a spatially explicit framework for Levin (1969)'s metapopulation model,

$$\frac{dp(t)}{dt} = c[1 - p(t)] - ep(t) \quad Eq\ 3$$

where Hanski and Ovaskainen (2000) extended the core metapopulation equation to one for the probability of occupancy of individual patches:

$$\frac{dp_i(t)}{dt} = C_i[1 - p_i(t)] - E_i p_i(t) \quad Eq\ 4$$

A critical result was that Hanski and Ovaskainen (2000) were able to replace the a-spatial Levin's (1969) inequality for a viable population, where a percentage *h* of all patches is occupiable (not yet destroyed by human activity):

$$h > \delta = \frac{e}{c} \qquad Eq\ 5a$$

with a spatially-explicit inequality:

$$\lambda_M > \delta = \frac{e}{c} \qquad Eq\ 5b$$

where λ_M is what Hanski and Ovaskainen (2000) defined as the "metapopulation capacity." In both inequalities, *e* represents the rate of extinction for all patches and *c* the rate of colonization for all patches.

In Levin's (1969)'s original formulation, *h* is essentially a-spatial; it is a range-wide average of occupiable habitat. In the approach of Hanski and Ovaskainen (2000), λ_M the metapopulation capacity, is derived from a matrix that depends on the size and positions of the patches, and a dispersal distance *L* that represents how far a species member travels. The value of this inequality is that λ_M and the condition for population viability, *e*/*c*, are directly relatable to habitat fragmentation, and any additional fragmentation of the population is reflected in a calculable reduction in λ_M.

The drawbacks of using Hanski and Ovaskainen (2000)'s metapopulation approach for this project is that the desert tortoise does not live in nicely distinct patches, so *e* and *c* are hard to define operationally. More critically, the general lack of range-wide data on patch rescue for the desert tortoise makes it impossible to estimate the ratio *e*/*c* using the techniques that Hanski and Ovaskainen (2000) pioneered.

3.5.2.2 Individual Territory Model

Noon and McKelvey (1996) built on work by Lande (1987) to show that the "individual territory model" (ITM), where the landscape is assumed to be tiled by individual home ranges, leads to an expression for the equilibrium proportion of occupied home ranges that is identical, in terms of mathematical structure, to the estimate from Levin (1969)'s equation:

$$\hat{p} = \left[1 - \left(1 - \frac{1-s}{b}\right)^{1/n} / h\right] \quad Eq\ 6$$

with a corresponding condition for viability:

$$h > \tau = \frac{1-s}{b} \qquad \textit{Eq 7}$$

The role of extinction *e* in metapopulation dynamics is taken by the mortality rate of an individual territory holder *1-s*, where s is the survival rate of adult females. The role of colonization *c* in metapopulation dynamics is taken on by *b*, the per-individual birthrate. For Noon and McKelvey (1996), metapopulation models and ITM are structurally equivalent, but model different spatial scales: subpopulation patch versus individual territory.

The advantage of ITM for the desert tortoise is that *s* and *b* are quantities that have been estimated. In addition, ITM assumes a tiled, continuous landscape description, not isolated habitat patches connected by long-distance migration. The drawback is that Noon and McKelvey (1996)'s treatment of the ITM is essentially a-spatial.

The approach in this project was to formally extend the ITM to a spatial model, which enables the use of the spatial concepts of Hanski and Ovaskainen (2000) to arrive at a concept λ_P (the *Population Capacity*) which can be used to test population viability:

$$\lambda_{PC} > \tau = \frac{1-s}{b} \qquad \textit{Eq 8}$$

3.5.2.3 A Spatial Implementation of ITM

The project partners started with a reformulation of the Levin's metapopulation equation as an equation for the probability of occupancy of *individual territories*, p_i.

$$\frac{dp_i(t)}{dt} = I_i[1 - p_i(t)] - (D_i)p_i(t) \qquad \textit{Eq 9}$$

where:

- I_i is a term expressing the immigration into an unoccupied territory by juveniles from nearby territories, where the immigration is a supported by births in the nearby territories; and
- D_i is the mortality of adult females in occupied territories.

The partners then followed the exact progression of Hanski and Ovaskainen (2000) as in Table 11 below. By adhering to a tiled coverage where each tile is an individual home range (equivalent to an individual territory), the parameters for adult survival *S* and reproduction *B* for an area become the individual rates *s* and *b*. This approach proceeds with all areas A_j being a fixed tile area of the home range, but also keeps a small a_j for each tile, which represents a fractional area of the tile if there has been complete habitat loss in some portion. For instance, if part of the territory is intersected by the boundary fence of a solar energy site, only the accessible portion of the hexagon is retained for the territory; this reduced area is then properly represented in the calculation of the *Population Capacity* λ_{PC}. AHP was used as a proxy for both habitat quality and resistance to movement in all equations above: $a_j \rightarrow AHP_j * a_j$, $d_{ij} \rightarrow d_{ij}/AHP_j$.

This approach does not formally include the search of n territories that a juvenile undertakes, which is one aspect of Noon and McKelvey's (1996) ITM extension of Levin (1969). In this spatially explicit formulation, the exponential decay term $\exp(-d_{ij}/L)$ in the influx means that a juvenile only gets to move to a small number of nearby home ranges.

Table 11: Illustration of Population Capacity Method Combining Metapopulation and Individual Territory Models

Metapopulation capacity	ITM	Population Capacity λ_{PC}.	Notes
$\frac{dp_i(t)}{dt} = C_i[1-p_i(t)$	None	$\frac{dp_i(t)}{dt} = I_i[1-p_i(t)] - (D_i)p_i(t)$	Change in probability that a tile (= home range) is occupied. Immigration into empty tiles vs. mortality in occupied tiles
$E_i = e/A_i$	**1-s**	$D_i = (1-S)/A_j \gg (1-s)/a_j$	Mortality in an area is *1 – S*, survival rate. *S* can be identified as *s* if the tile area is the home range.
$C_i = c\sum_j exp(-\alpha d_{ij})$	**b**	$I_i = \sum_j exp(-d_{ij}/L)A_j\left(Bp_j(t)\right)$ $\gg b\sum_j exp(-d_{ij}/L)a_j p_j(t)$	Immigration depends on births in adjacent, occupied tiles. *B* can be identified as *b* if tile area is home range.
$m_{ij} = \exp(-\alpha d_{ij})A_i$ $if\ i \neq j$		$m_{ij} = \exp\left(-\frac{d_{ij}}{L}\right)a_i a_j$ $if\ i \neq j$	Population Capacity $\lambda_P$is principal eigenvalue of the connection matrix *M*.
$\lambda\_M > \delta = e/c$	$h > \tau =$	$\lambda_{PC} > \tau = \frac{(1-s)}{b}$	A condition for viability that relates habitat fragmentation to individual rates.

The last inequality from Table 11, which is Equation 8 above, is very significant to the analysis of population fragmentation for the desert tortoise. As in Equation 5a and b, the left hand side is a metric based on the quality of the habitat (natural and anthropogenic) and the underlying *topography* of the landscape, mediated by a characteristic travel distance L of the species. Meanwhile the ratio on the right hand side depends only on demographic rates of the species - the mortality rate *(1-s)* divided by the birth rate b - a ratio whose inverse Noon and McKelvey refer to as the demographic potential of the species. If the *Population Capacity* can be calculated for the tiled landscape, its value when compared to the demographic potential would indicate area where habitat has been so degraded that the population is no longer viable there.

3.6 Implementing Spatial Calculations

An approximate implementation of the *probability of connection index (PC Index)* is to estimate the most probable path between patch *i* and patch *j*, as the straight line from the centroid of one to the centroid of the other.

As the equations below show, the same dimensionless connection matrix then supports both habitat fragmentation metrics: *PC Index* (albeit with direct line paths only); and *Population Capacity.* AHP provides both an inverse measure of resistance and a measure of habitat quality for both metrics.

$$\boldsymbol{M_{ij} = A_i * AHP_i * A_j * AHP_j * exp(-\sum_{k=0}^{n}(D_k/AHP_k)/L)} \qquad \textit{Eq. 10}$$

For a tiled landscape, and with the extra assumption of no clipping, $\boldsymbol{a_j}$**=1 for all j,** the area of every patch is the same: $\boldsymbol{A_{HEX}}$. The team defined the dimensionless connection matrix $\boldsymbol{\widehat{M}_{ij}}$, as:

$$\boldsymbol{\widehat{M}_{ij} \equiv \frac{M_{ij}}{A_{HEX}^2} = AHP_i * AHP_j * exp - (\sum_{l=0}^{k} \frac{ED_l}{AHP_l})/L) \ \ when\ i \neq j, else\ 0} \qquad \boldsymbol{Eq\ 11}$$

The probability of connection with straight-line paths is then:

$$\boldsymbol{PC^* = (\sum_i \sum_j M_{ij})/A_R^2 = (\sum_i \sum_j \widehat{M}_{ij}) * (\frac{A_{HEX}^2}{A_R^2}) = (\sum_i \sum_j \widehat{M}_{ij})/N^2} \qquad \textit{Eq. 12}$$

and the Population Capacity metric is:

$\boldsymbol{\lambda_{PC}}$ $= \textit{principal (largest positive) eigenvalue of the off} - \textit{diagonal,}$
$\textit{dimensionless connection matrix } \boldsymbol{\widehat{M}_{ij}} \textit{ when } i \neq j, \textit{but } 0 \textit{ when } i = j$

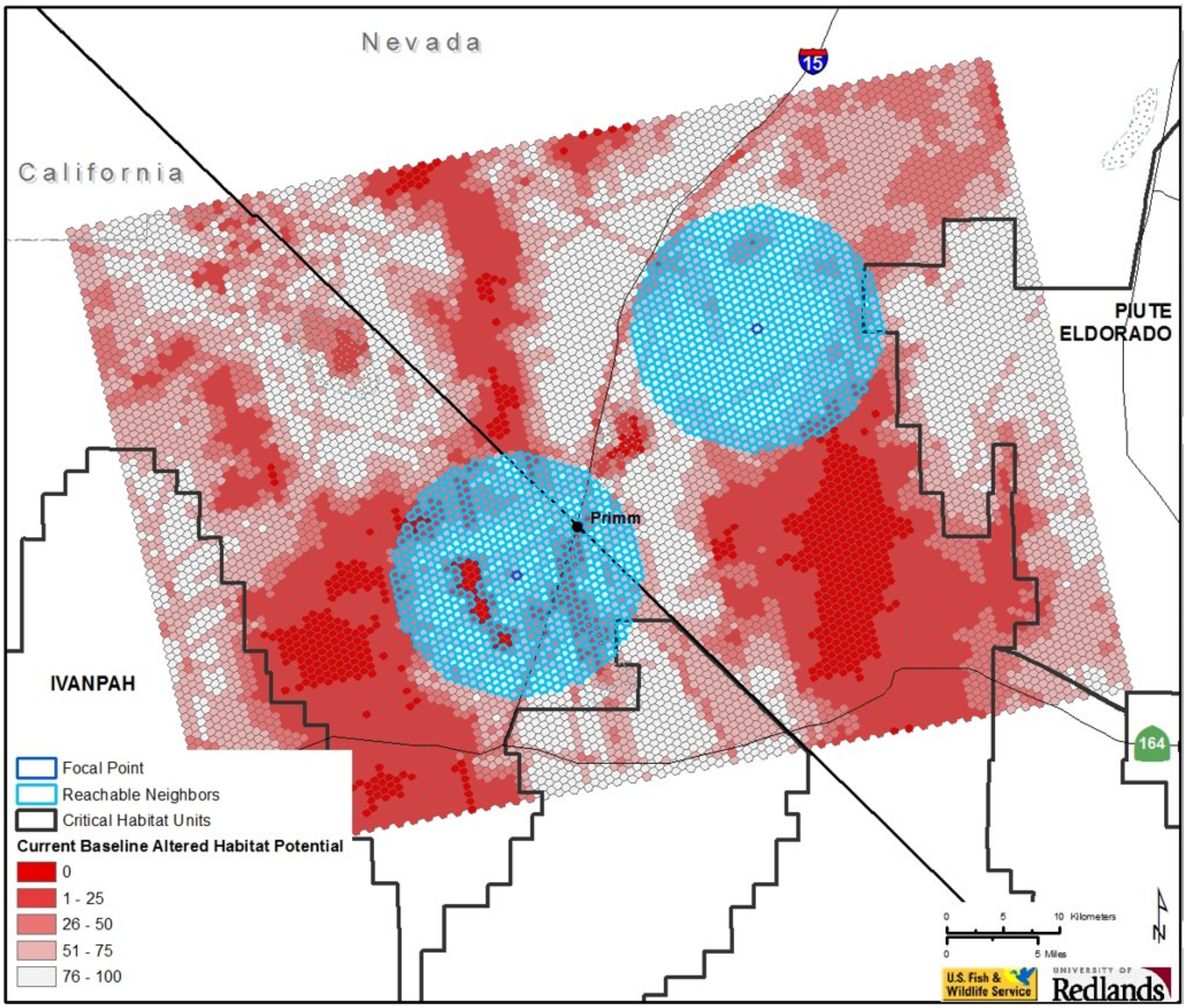
3.6.1 *Effective Distance* Calculation

The part of the connection matrix *Mij* which must calculated spatially is the *effective distance (EDij)* between any starting territory *i* and any ending territory along a straight-line path that traverses *k* intermediate territories. This effective distance is a cost distance: the difficulty (*resistance)* that a tortoise has to overcome, when traversing areas with varying degrees of habitat potential. Within each territory, the Euclidean distance of the path across that territory is multiplied by the average value of the AHP of the territory, the latter being an estimate of the resistance to travel across the territory.

Figure 19 below shows the AHP values for a study area of 10,000sq km in the Ivanpah Valley. AHP is desert tortoise habitat potential (USGS 2009) modified to reflect anthropogenic features on the landscape. Those areas with zero AHP, like those areas in the darkest red (such as the ISEGS solar power plant), have no possibility for tortoise passthrough or habitation.

It is important to have these two concepts in the definition, because desert tortoise is a slow moving animal, and on average, a juvenile female tortoise will travel up to 10 km before settling to nest and reproduce. When a territory becomes uninhabited and a dispersing individual happens upon that site, rescue can happen. To characterize the probability of travel, 10 km was set as the distance threshold *L*, which is the lifetime travel distance of a female desert tortoise.

Figure 19: AHP Values for Ivanpah Valley Study Area



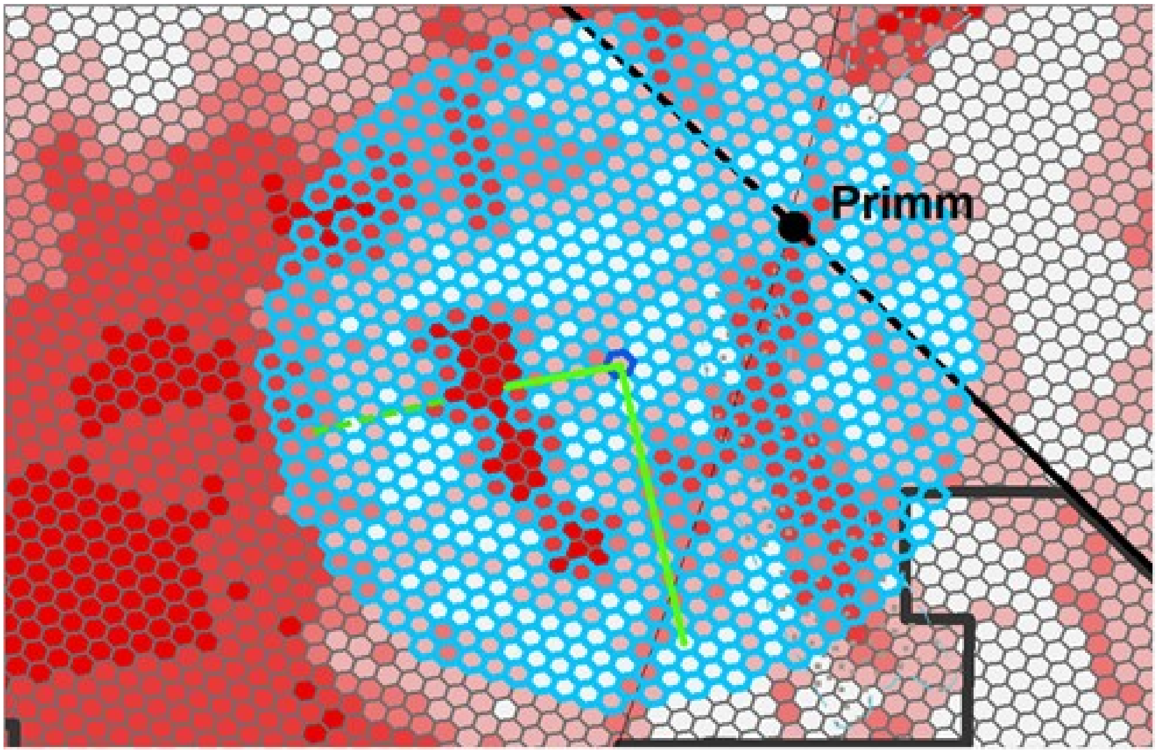
Blue hexagons are possible reachable territories for a tortoise located at the dark blue focal hexagons. In this map, darker red patches are areas of low AHP through which a desert tortoise would be unable to travel. The three impassable red areas in the lower left disk are the fenced mirror fields and infrastructure of the actual ISEGS plant.

Source: Desert Tortoise SDSS

As an example, in Figure 19, if you take the center of each of these blue circles to be a starting point *i*, you see that all the blue areas are possible reachable territories *j*, for a tortoise. The life time travel distance for a tortoise, 10km, defines the limit of reachable territories.

Upon closer examination of a few possible paths (Figure 20), the tortoise could potentially get to any area where it does not encounter an impassable zero AHP hexagon in its direct line of travel. This first cut of calculations uses Euclidean distances, which may be refined in later iterations with least cost paths. When the tortoise hits a zero AHP tile, that path is not considered in the calculations.

Figure 20: Possible Reachable Territories Using Euclidean Distance Calculation of Potential Direct Lines of Travel

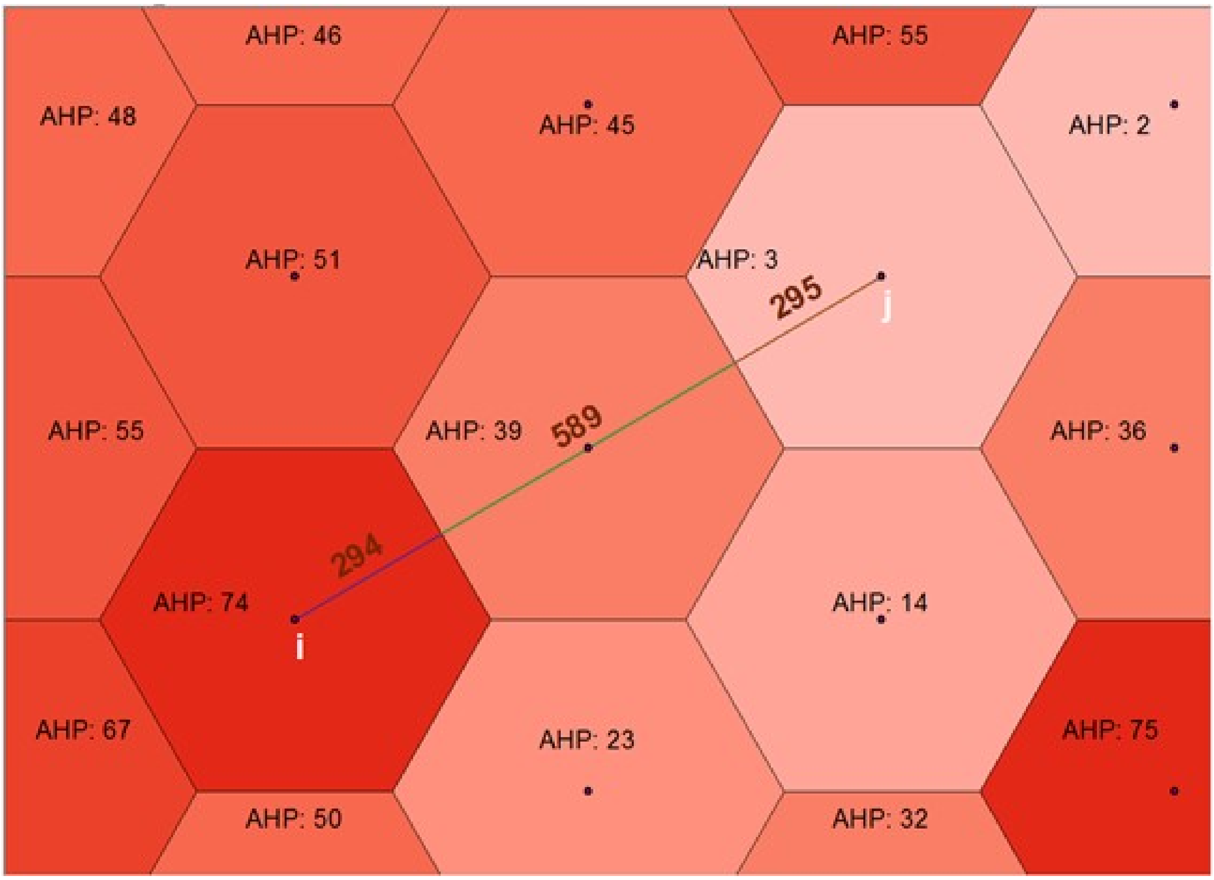


Close-up view of possible reachable territories for a tortoise starting at the dark blue focal point. Darker red patches have low AHP and would be less traversable for the tortoise. Potential lines of travel include any direct line in which the tortoise does not cross an impassable zero AHP hexagon. The broken line east of the dark red (AHP=0) ISEGS area indicates connections that cannot be made with a direct line model.

Source: Desert Tortoise SDSS

The effective distances between two territories is calculated spatially by generating a straight line between the centroids of the starting *(i)* and ending *(j)* territories (hexagons), and intersecting that line with the edges of the hexagons to get individual line segments (Figure 21).

Figure 21: Example of Effective Distance Calculation



Example of calculation of effective distance (*ED*) between two territories (*i*) and (*j*) as the sum of the lengths through each connected hexagonal tile, times the resistance to movement in each cell.

Source: Desert Tortoise SDS

The effective distance of the path is calculated by (1) multiplying the length of each segment in meters (brown text in Figure 3.9), times the resistance to movement, which is the inverse of AHP for that segment; and (2) summing the effective distance of each segment. For the example in Figure 3.9 (note that AHP values shown are 100 times actual AHP), this produces the following computation:

$$EffD_{ij} = (\sum_{k=1}^{n} \frac{D_k}{AHP_k} = \frac{294m}{0.74} + \frac{589m}{0.39} + \frac{295m}{0.03} = 11{,}741\ m \gg 294 + 589 + 295 = 1{,}178\ meters$$

The effective distance calculation was computed for every possible pair of starting and ending territories within the length *L*; excluded were paths blocked by impassable and uninhabitable areas. This produced 30 million possible paths and effective distances within the Ivanpah Valley study area, which itself is roughly one tenth of the entire desert tortoise range.

3.6.2 Summary of Spatial Calculations

To summarize, the six steps in implementing the spatial calculations were:

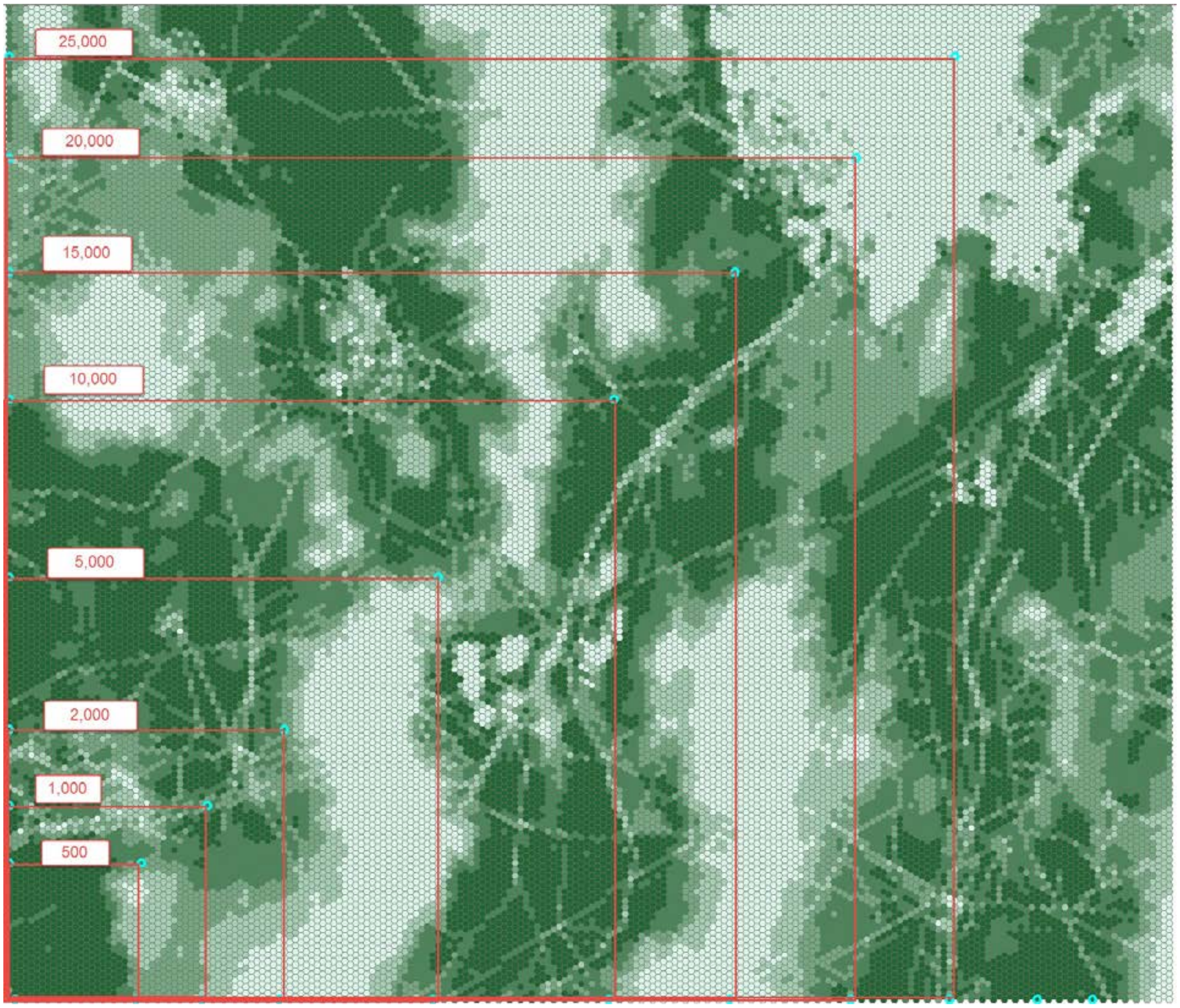
1. Create hexagon tiling for study area (33 thousand 30.4ha hexagons)
2. Calculate average *altered habitat potential (AHP)* for each hexagon
3. Calculate the *effective distance (ED)* between each pair
    a. but only consider distance < 10km, the life time travel distance
    b. produces > 30million connected pairs
4. Calculate the *connection matrix Mij*
5. Calculate *probability of connection index (PC Index)*
6. Calculate *Population Capacity* λ_{PC}, the principal eigenvalue of the connection matrix *Mij*
    a. *M* has a billion, generally empty (not connected) entries
    b. Use the efficient Lanczos Algorithm for calculating principal values of large but sparse symmetric matrices

Steps 1-3 were executed in python scripts that accessed ArcGIS geoprocessing services. Steps 4-5 were performed in Microsoft SQL Server and the last step calculating the eigenvalue for an almost 1 billion element sparse matrix, was successfully executed using the open source SciPy library for scientific computing (source: http://www.SciPy.org).

3.6.3 Area Scaling Analysis of Metapopulation Approaches

To better understand the properties of the approach outlined above to calculate the two metapopulation metrics, the team developed a set of square subareas of the Ivanpah Valley study area (Figure 22). The areas all had their southwestern points set at that corner of the overall study area, and hexagonal tiles were selected using a geometric algorithm to create ever larger, roughly square areas.

Figure 22: Nested Squares Used for Exploring Scaling Properties of Metapopulation Metrics



The smallest square contains 500 30.4 ha hexagons, the largest 25,000. The entire study area is covered by 33,284 hexagons.

Source: Desert Tortoise SDSS

The PC*Index and Population Capacity metric were estimated for each of these areas using the computational methods described in this section.

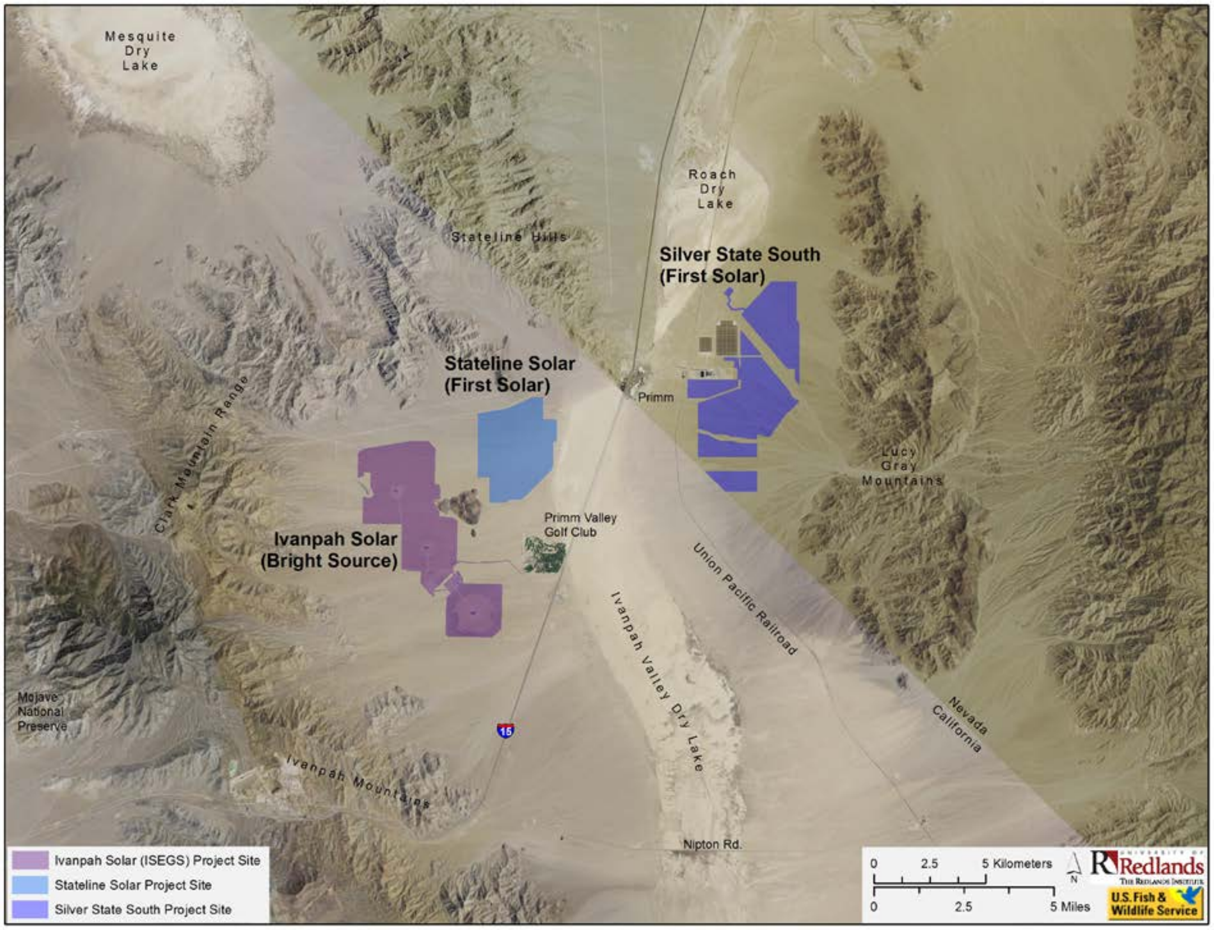
3.7 Results of Metapopulation Approaches

3.7.1 Probability of Connection Index and Population Capacity Results for Ivanpah Valley Study Area

The project team executed the above spatial calculations for each of the three scenarios in the Ivanpah Valley study area: (1) Pre-Columbian, (2) Post-Brightsource ISEGS Baseline, and (3) ISEGS with Projected First Solar Stateline and Silver State footprints (3 Solar Scenario; Figure

23). For "Pre-Columbian" the team used the USGS Habitat Potential directly, which did not include any direct anthropogenic alternations to the landscape.

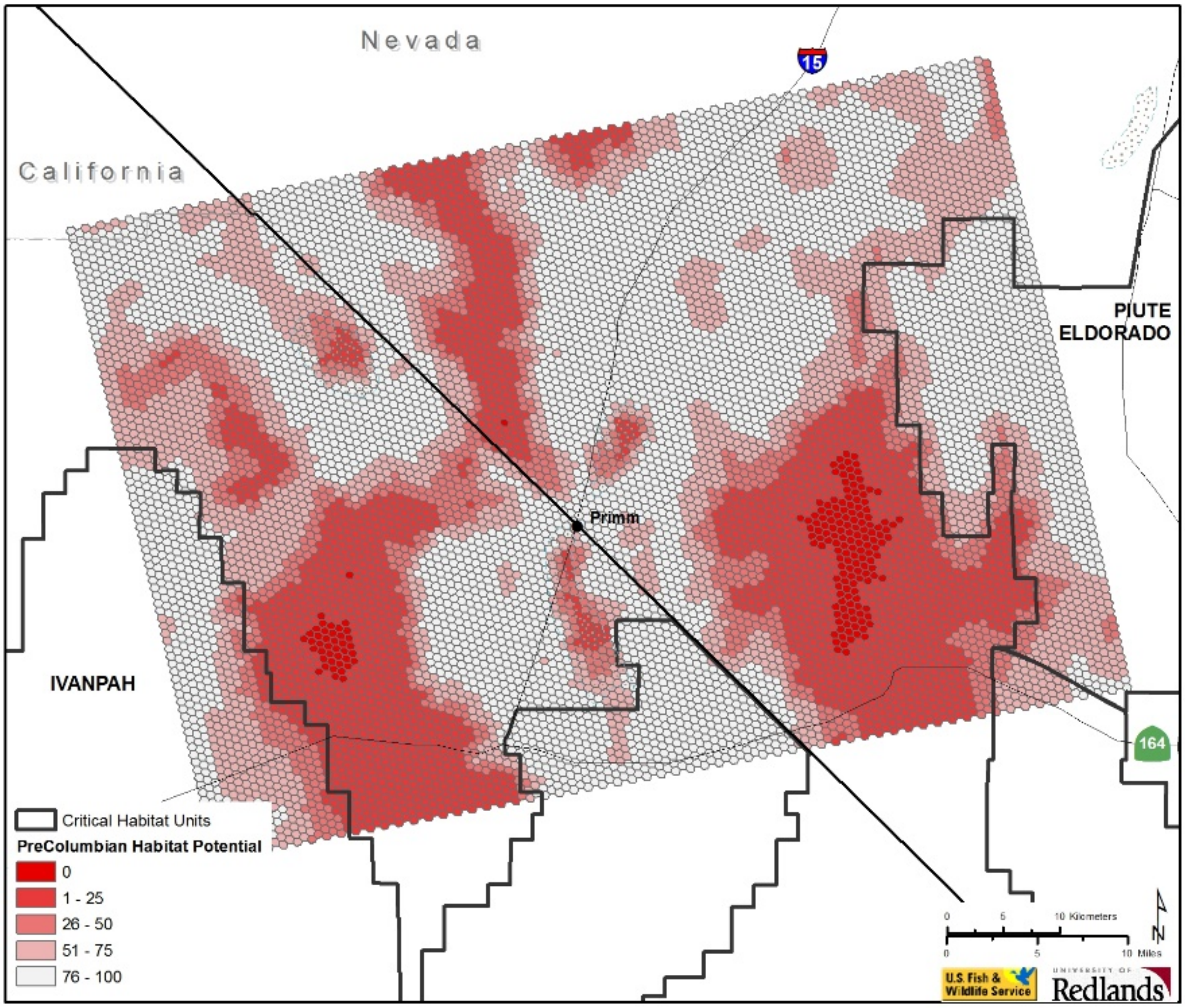
Figure 23: Map of 3 Solar Scenario Showing Location of ISEGS, Solar Stateline and Silver State Footprints



Source: Desert Tortoise SDSS

These scenarios sequentially add more disturbance to the habitat, as is revealed by comparison of their respective maps of AHP (Figures 24-26). In Pre-Columbian times, there were broad corridors of relatively high habitat potential emerging from the modern day Ivanpah critical habitat unit and traversing northeast through the Ivanpah Valley on both sides of a low range of hills that runs along the center of the valley, touching the edge of the modern day Piute Eldorado critical habitat unit and continuing onwards towards the northeast.

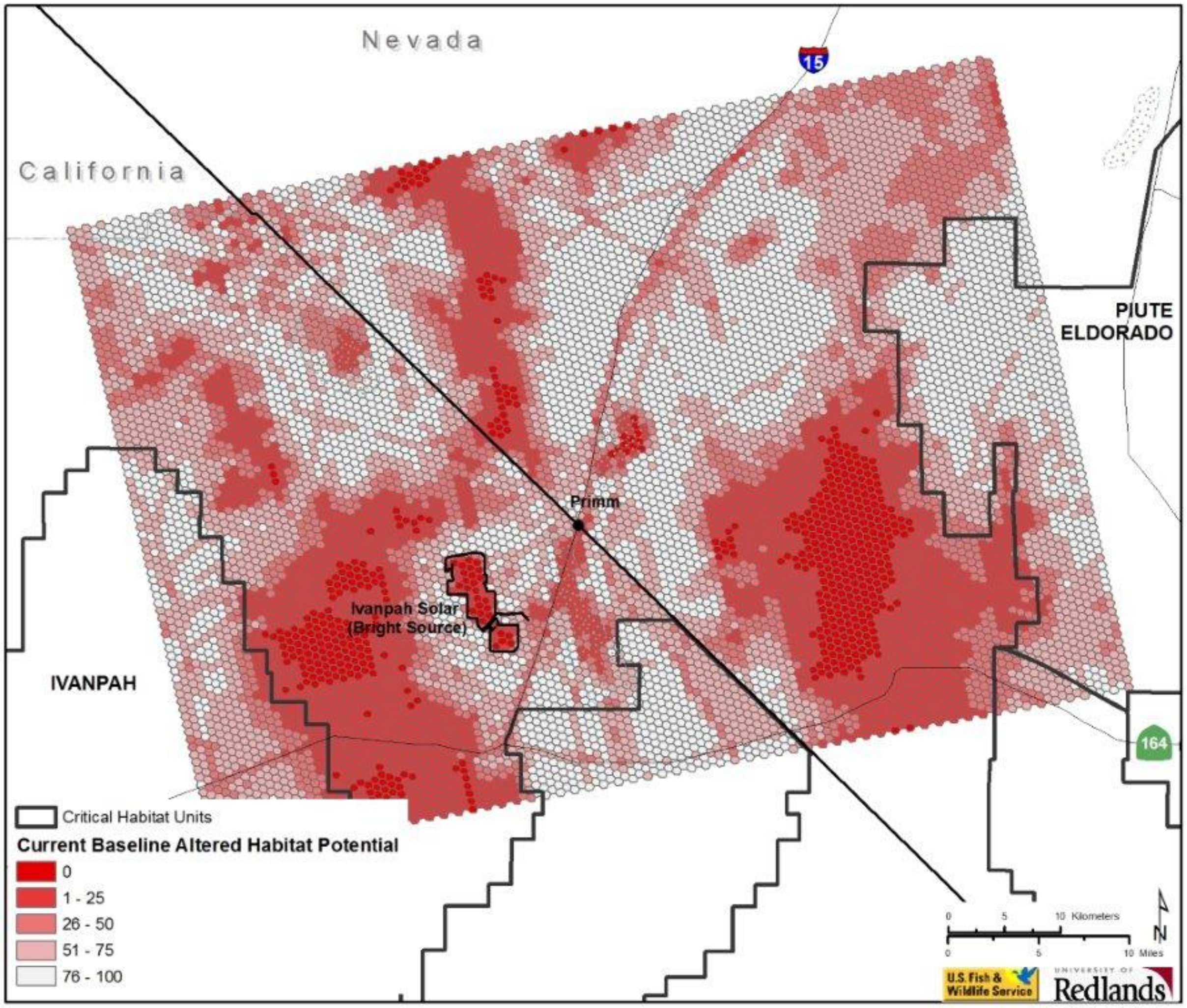
Figure 24: Altered Habitat Potential for Pre-Columbian Era



In this Pre-Columbian scenario, the high resistance areas have higher elevation. Also shown are the outlines of the two nearest desert tortoise critical habitat unit areas: Ivanpah and Piute-El Dorado. Figures 3.13 and 3.14 below show the cumulative decrease in habitat potential resulting from the addition of the (3.13) ISEGS and other anthropogenic disturbances to 2014, and (3.14) the proposed Silver State and First Solar Stateline project footprints to the landscape.

Source: Desert Tortoise SDSS

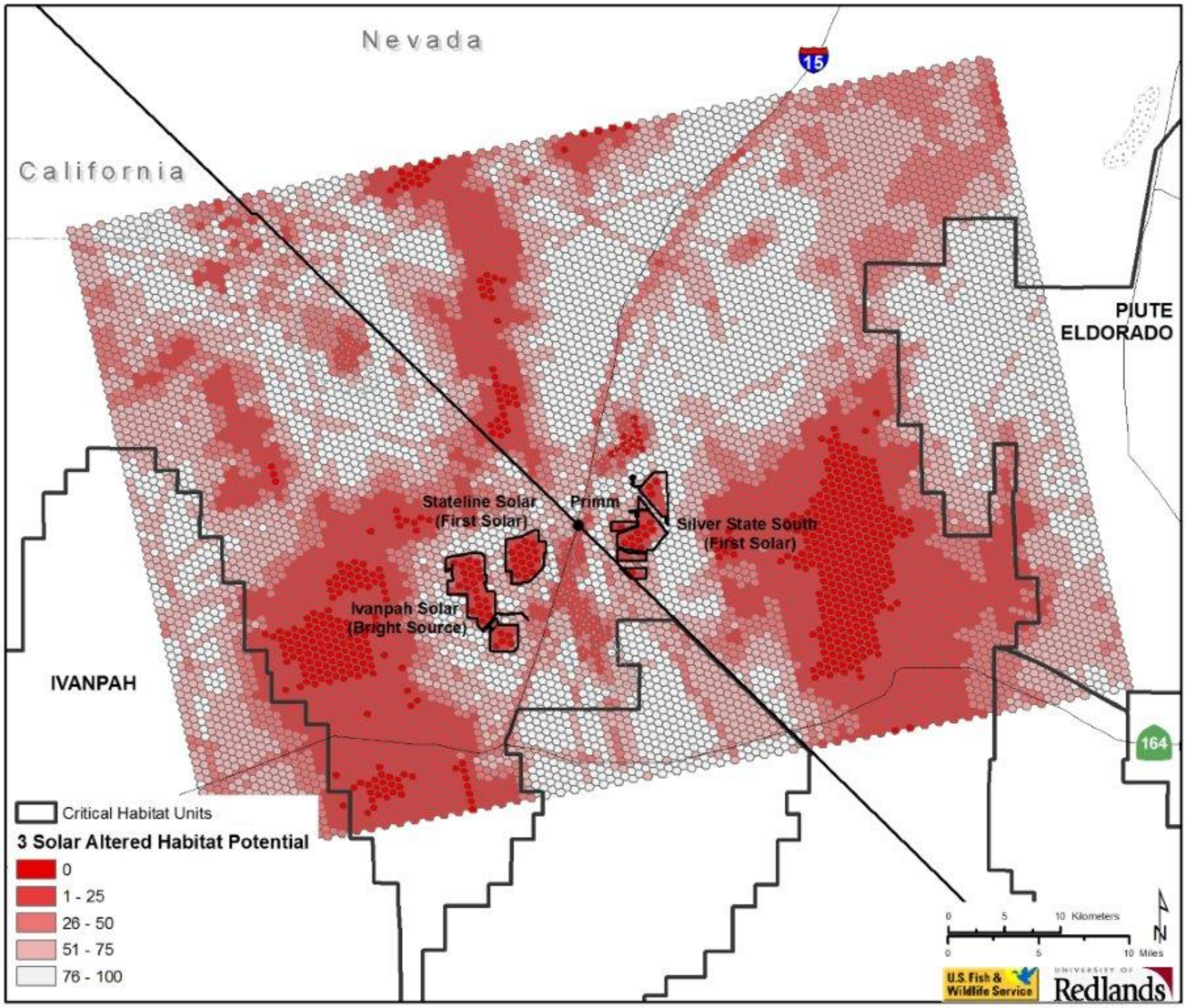
Figure 25: Altered Habitat Potential for Baseline Post-Brightsource ISEGS Scenario



Results of calculation of AHP for desert tortoise, under the post-Brightsource ISEGS scenario, which includes the ISEGS project footprint (smaller polygons outlined in black) and other modern development. Darker red are areas with less AHP (more resistance to dispersal), which on this map include both natural and human-made barriers.

Source: Desert Tortoise SDSS

Figure 26: Altered Habitat Potential with Addition of First Solar Stateline and Silver State Project Footprints (3 Solar Scenario)



Results of calculation of AHP for desert tortoise including both ISEGS and the addition of projected First Solar Stateline and Silver State footprints (smaller polygons outlined in black).

Source: Desert Tortoise SDSS

As expected, both indices show significant decreases from their Pre-Columbian state. If the entire study area was made up of hexagons with perfect AHP and a tortoise in its lifetime could traverse from one end to the other, the PC Index would be 1. Using the USGS Habitat Potential itself for AHP as characterizing the landscape in Pre-Columbian times, the finite travel distance and natural elevations of the Ivanpah Valley area, result in a PC* Index far below 1 even in that scenario. Treating that value of the PC* Index, and the corresponding estimate of the Population Capacity for that scenario as 100%, Table 12 shows how the increasing fragmentation of the subsequent scenarios reduces both metrics. With all the anthropogenic disturbance to the valley up to this time, including the building of the Brightsource ISEGS plant, the value of the PC Index fell by 40.8% and the Population Capacity by 15.1%. The final scenario that adds hundreds of hectares of development in the form of the two proposed solar energy plants (Silver State and First Solar Stateline) reduces PC* Index by a further 2.8% and Population Capacity by 2.1%.

Table 12: Results for PC Index and Population Capacity λ_{PC} for the Three Study Scenarios

Scenario	PC^* Index	% Pre-Columbian	λ_{PC}	%Pre-Columbian
Pre-Columbian	0.005732	100.00%	336.20	100.00%
Baseline ISEGS	0.003394	59.20%	285.39	84.89%
3 Solar Plants	0.003236	56.45%	278.33	82.79%

Source: Desert Tortoise SDSS

Both the PC Index and Population Capacity metrics showed significant change from the Pre-Columbian scenario (the original USGS habitat potential layer) to the current state with all anthropogenic disturbance captured in the AHP layer. Projecting forward, adding two proposed solar energy development plants that would destroy all burrows within perimeters that surround about 2000 acres, or 0.1% of the Ivanpah Valley study area, resulted in more than a 2% drop in the Pre-Columbian value for both metrics. Clearly the changes in both metrics reflect more than just the fraction of area lost from the habitat, which was what the old model for population fragmentation reflected.

3.7.1.1 Sensitivity to Topography

The key test of the usefulness of a metric for landscape fragmentation is whether the removal of territory with the same area and habitat quality in an obviously constricted (be it by mountains, cliffs, raised road beds, tortoise proof fencing, etc.) linkage of the range, has more impact than the loss of a similar territory (in terms of size and quality) in an open area of the range. In Table 13, the values in Table 12 are used to calculate the change between scenarios, as a percentage of the Pre-Columbian value of each metric per unit change in the average AHP value.

Table 13: Sensitivity of Metrics to Change in Habitat in Topographically Constricted Areas

Scenario progression	Drop in Average AHP	Drop in PC Index	% drop in PC Index per unit drop in AHP	Drop in Population Capacity	% drop in Population Capacity per unit drop in AHP
Pre-Columbian > 2014 Baseline	11.806	0.002339	3.46%	50.80	1.28%
2014 Baseline > 3 Solar Projects	0.160	0.000158	30.61%	7.07	15.92%
	sensitivity ratio		8.86		12.44

Source: Desert Tortoise SDSS

In the next analysis, changes in AHP rather than area were employed as the independent variable. Reduced AHP accounts for both partial degradation of the habitat (see Section 3.3) as well as its absolute loss. In addition, while calculating the area lost to emptying, grading, and fencing a solar energy project is relatively straightforward, estimating an area loss associated with all the myriad of other anthropogenic changes occurring from the Pre-Columbian to the current Baseline scenario would require some interpretation.

The drop in PC index when the two proposed solar energy projects were added to ISEGS in the study area was almost 9 times larger per unit drop in average AHP than that estimated for the drop from the Pre-Columbian to the 2014 Baseline scenario. The corresponding ratio for Population Capacity is almost 12 times larger. Both metrics show a much greater sensitivity to loss of habit potential in a topographically constricted region of the landscape. The ratio values indicate that Population Capacity is somewhat more sensitive than PC Index to the relatively small change in average AHP that would occur if the two extra solar projects were introduced.

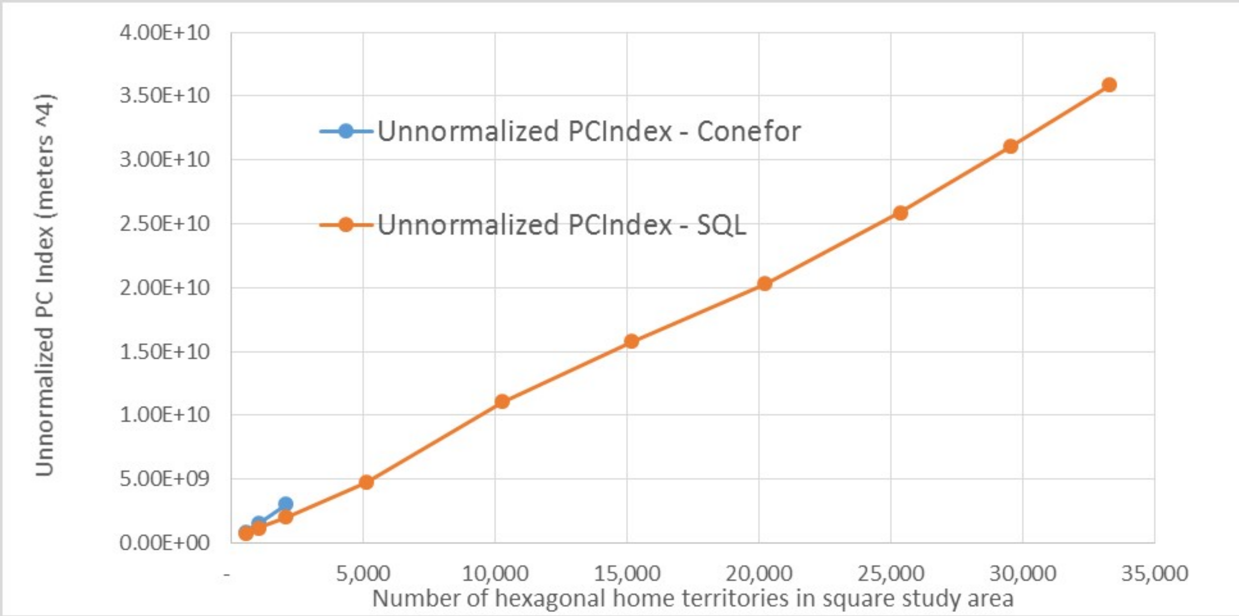
This conclusion might be missed because the percent change in value of the PC Index is larger than that of Population Capacity. This invites inquiry about why the absolute values for the two metrics are in the order of magnitude shown in Table 12.

3.7.1.2 Absolute Values of the Metrics and Scaling with Range Size

Indices such as the PC Index, which are based on summing over all pairs of patches, are expected to grow as the square of the range (if the patches are roughly evenly distributed). Accordingly, Saura and Pascual-Hortal (2007) divided this double sum by the square of the area of the entire range in their general definition for PC Index (see Equation 1 above). Consequently, doubling the range may not double the PC Index. Indeed, the scaling properties of the PC Index for the tiling approach of this analysis produce quite the opposite.

Using the nested “square” areas shown in Figure 22, the un-normalized value of the straight-line PC Index was calculated for a nested set of squares of hexagonal territories (Figure 27).

Figure 27: Scaling of Straight Line PC Index in a Tiled Landscape (3 Solar Scenario)



Results for the un-normalized PC Index (*UnPC)* as calculated in *Conefor* v 2.6 are shown in blue, results using *Microsoft SQL* are in orange. Conefor encountered memory issues with more than 2,000 territories.
Source: Desert Tortoise SDSS

The un-normalized PC Index, *UnPC*, is defined as a (dimensionless) index as:

$$PC^* = \sum_i \sum_j (\widehat{M}_{ij}) * \left(\frac{1}{N^2}\right) = UnPC^*/N^2 \qquad Eq\ 13$$

Where $\ddot{M}_{ij}$ is the dimensionless connection matrix from Equation 12.

And so

$$UnPC^* \equiv \sum_i \sum_j (\widehat{M}_{ij}) \qquad Eq\ 14$$

Results for the unnormalized PC Index (*UnPC*) from N=500 to N=33,000 are shown in Figure 3.15. Clearly *UnPC* increased linearly with *N*. This means that PC Index itself, which is obtained by dividing *UnPC* by $\boldsymbol{N^2}$ will fall as *N* (and the study area) increases.

PC Index drops as the area grows, due to the finite migration distance *L* of the females in this tiling approach, as used in the exponential decay formulation of travel probability in Equations 10a, 12 and 13. In a perfect habitat landscape, where AHP = 1 everywhere, for any given territory *i*, the female tortoise could reach all hexagons within radius *L*, which if the area of the hexagon is small compared to L^2, means that the female at every home territory could reach, integrating the exponential decay term, $N_L = 2\pi L^2/A_{HEX}$ other territories.

$$UnPC(AHP = 1, A_{HEX} < L^2) = \sum_i (\sum_j (\widehat{M}_{ij})) = \sum_i N_L = N * N_L \quad \text{Eq 15}$$

If there were perfect habit throughout the range, *UnPC* would scale linearly with *N* as more territories are added to the study area.

How the Population Capacity scales as the study area increases is more interesting. The results from the scaling simulation are displayed in Figure 28.

Figure 28: Scaling of Population Capacity in a Tiled Landscape

Results for Population Capacity for a sequence of nested “squares” of hexagons (see Figure 3.10). The blue line shows the value of Population Capacity increasing slowly with larger area. The orange line shows the average value of AHP over each hexagon square.

Source: Desert Tortoise SDSS

Population Capacity increases slowly with increasing study area size, increasing by only 27% as the area of the study area increases from 3000 sq km (N=10,000) to 10,000 sq km (N=33,000).

It is clear from Figure 3.16 that the value of Population Capacity is not driven by overall average AHP value. This means that destroying habitat on a local scale will not register on the range-wide average AHP. Yet a useful population fragmentation metric needs to be particularly sensitive to losses in habitat in regions of the landscape that are constricted by landscape topography.

The early increase for N=1000 and N=2000 is dominated by edge effects. Examining the graph and the map in Figure 3.10 together, it can be seen that Population Capacity plateaus when the added areas contain many hexagons that border areas with low AHP (e.g., along both sides of the mountains to the West of the Ivanpah Valley (e.g., between N=2000 square and the N=5000 square), and then increases again when the added area is primarily made up of moderate quality habitat (e.g., between the N=5000 and N=10,000).

That the graph does grow so slowly is critical if the inequality expressed in Equation 8 can have any meaning. If all that was needed to satisfy that condition for viability was to add enough habitat, the desert tortoise with its huge range would undoubtedly do so. In an ideal case where a female tortoise can migrate an infinite distance, and has perfect habitat potential throughout its range, then $\boldsymbol{\widehat{M}_{ij} = 1\ if\ i\ \neq j, and\ 0\ if\ i\ = j.}$ In this case, the characteristic equation for an *N x N* matrix with elements of that form is $(\lambda + 1)^{n-1} * (\lambda - (N - 1)) = 0$, so the principle eigenvalue would be $\lambda_p = N - 1$. Population Capacity, in that fully connected, tiled range would grow linearly with *N*, and hence area. In reality, however, the elements in $\boldsymbol{\widehat{M}_{ij}}$ are reduced both by less than perfect AHP and by the finite migration distance *L.*

3.7.1.3 Is Population Capacity Ready to be Used to Test Viability?

The relative scale invariance of Population Capacity, taken together with its sensitivity to the destruction of topographically critical home territories, makes it a good candidate metric for population fragmentation. The question remains whether it also provides the test of population viability, as promised by Equation 8.

Reviewing the formulae underlying the ITM (Noon and McKelvey, 1996) in detail (which required some algebra corrections to the equations as written), the authors identified s as the average survival of adult females (15 years and older) and b as the probability of successful hatchling birth, survival and dispersal (to year 15) OR as the adult replacement rate. Directly using desert tortoise life tables (Turner et al., 1987), the authors, in consultation with DTRO experts, estimated s to be 0.951 and b to be between 2.393 and 0.067. These estimates yield a value for (1-s)/b in the range 0.02 – 1.355, four to two orders of magnitude less than those values of Population Capacity obtained in the Ivanpah Valley study area. Given that the tortoise populations are struggling in the Mojave Desert compared to other areas where the tortoise can be found, such as the Sonoran Desert in Arizona (Zylstra el. al, 2013), the team had hypothesized that the population capacity would be close to falling below the (1-s)/b threshold (Equation 8) at which level habitat fragmentation would leave the population unsustainable. That the value of Population Capacity as calculated is orders of magnitude larger than the threshold in this highly impacted corridor challenges the usefulness of this metric.

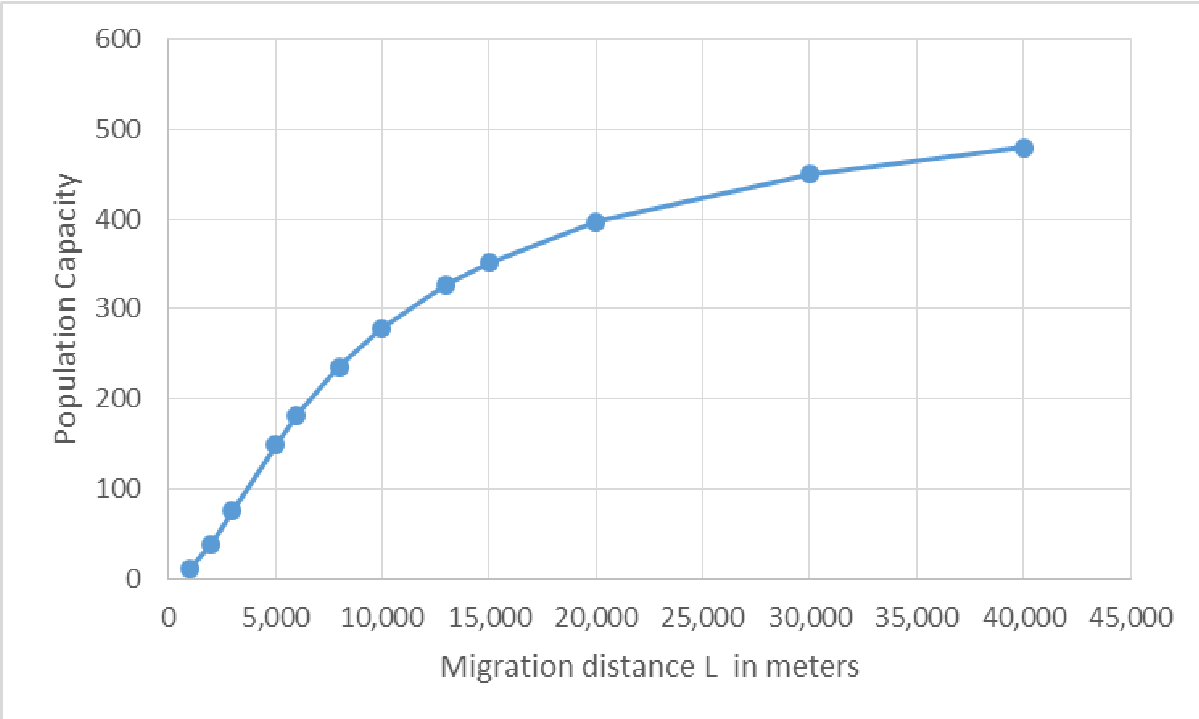
3.7.1.4 Why the Value of Population Capacity Hovers Between 150 and 300

The ratio on the right of Equation 8 is a dimensionless ratio of rates: death rates and birth rates for the adult females in the populations. Consequently, and keeping with the variable *h*, which represents the fraction of suitable territories in the ITM model (Noon and McKelvey, 1996), the dimensionless connection matrix $\boldsymbol{\widehat{M}_{ij}}$ is used as the basis for Population Capacity.

Hanski and Ovaskainen's (2000) connection matrix is the dimensioned matrix M_{ij} in Equation 10, which includes the product of area A_i of each patch. There is no area normalization similar to the range area term A_R used in the PC Index. Even with all tiles having the same areas, scaling all elements in $\boldsymbol{\widehat{M}_{ij}\ by\ A_{HEX}^2}$ (see Equation 13) would scale the eigenvalue by the same factor. The team believes the dimensionless matrix is the appropriate characterization of the connectivity matric for this Population Capacity metric, but intends to continue to investigate the literature on metapopulation capacity.

The parameter that does drive the values obtained for Population Capacity is the lifetime migration range *L* of the female tortoises. The variation in Population Capacity in the 3 Solar Scenario with different values of *L* is shown in Figure 29.

Figure 29: Variation in Population Capacity Metric with Migration Distance *L*.



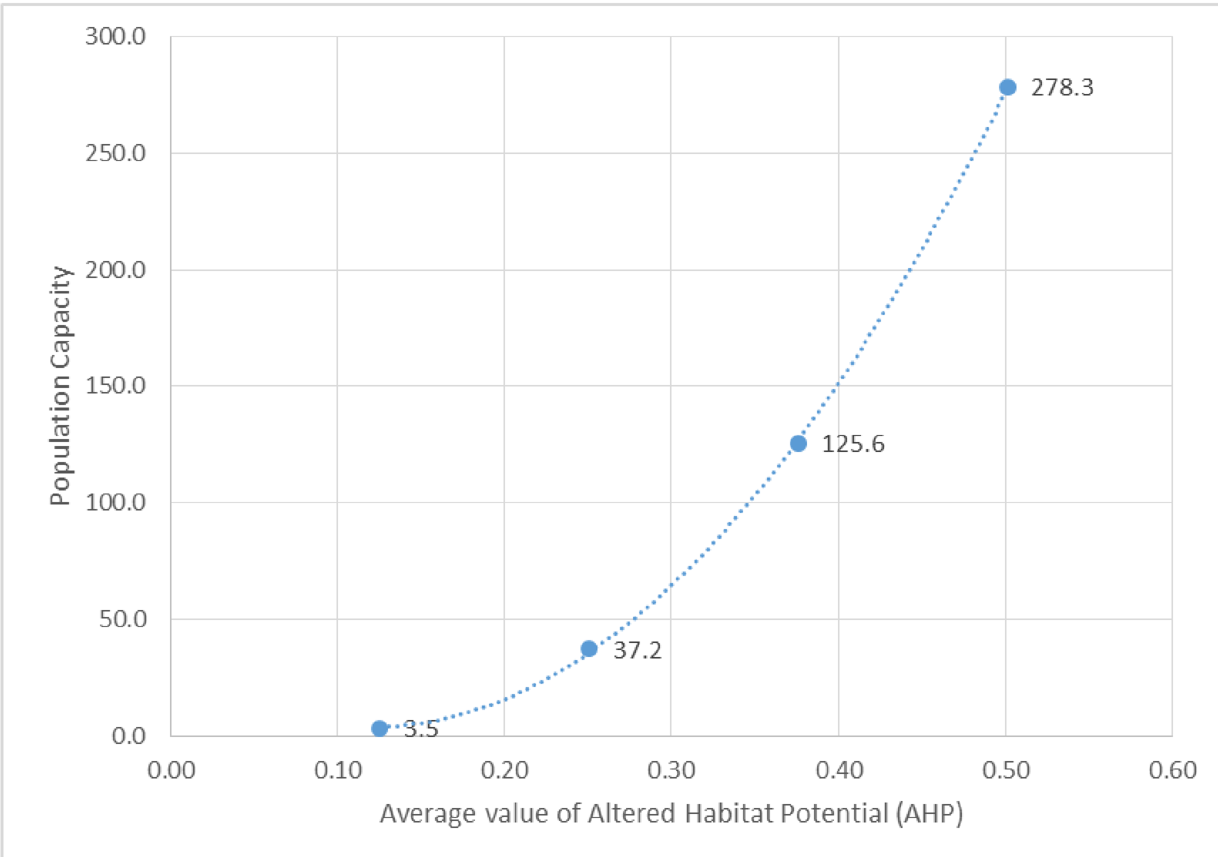
Graph showing the variation in Population Capacity metric for the full Ivanpah Valley study area with increasing values of the mitigation distance *L*. The estimate for *L* used through this chapter is 10,000m.
Source: Desert Tortoise SDSS

For values of *L* between 1000m and 6000m, Population Capacity increases linearly with migration distance *L*, then starts to level out. As the dimensions of the full Ivanpah study area are 92km North-South and 107km East-West, it seems clear that edge effects increase quickly for *L* greater than 10,000 meters. Literature suggests that the lifetime migration of a female tortoise is between 8 and 15 km. For all of those values, Population Capacity varies between 230 and 351, still about two orders of magnitude greater than the estimate of *(1-s)/b* for the desert tortoise. Only for migration distances of around 1km does Population Capacity approach single digits.

The final determining factor for the value of Population Capacity is the value of AHP used in both the connection matrix and as a proxy for resistance in the exponential decay term. In work directed by two of the authors (Cully et al. 2014), manual analysis of satellite imagery data was used to map the extent and type of anthropogenic disturbance in the linkages between tortoise critical areas (Averill-Murray et al. 2013). Preliminary results suggest that the NLCD 2011 data used in this analysis may at times account for only 25% of the observed disturbance. These preliminary results support independent field observations from FWS experts in the Ord-

Rodman to Joshua Tree and Fremont-Kramer to Ord-Rodman linkages. If all elements of a matrix are multiplied by the same constant, then so is the resulting principle eigenvalue. From the definition of the connection matrix, if the average AHP in the study area were to be reduced by 50%, this would result in the Population Capacity to fall by at least 75%. Uniformly reducing the AHP in the study area by 25%, 50% and 75% resulted in reducing the original Population Capacity from a value of 278.3 to values of a 125.6, 37.2 and 3.5, respectively (Figure 30).

Figure 30: Variation in Population Capacity Metric with Uniformly Scaled AHP.



Graph showing the variation in Population Capacity metric for the full Ivanpah Valley study area when the current values of average AHP for the territories are scaled uniformly, from current value (278.3) on the top right by 75%, 50% and 25%.

Source: Desert Tortoise SDSS

These reductions in AHP are within the range of corrections implied by the analysis of Cully et al. (2014) for current anthropogenic disturbance in critical habitat linkages. The values at the low end for Population Capacity are commensurate with the colonization potential *b/(1-s)*. Before accepting such adjustments to AHP, the manual image analysis of disturbance completed by Cully et al. (2014) should be extended to the entire desert tortoise range (at least areas with AHP > 0), and not just the linkages. In addition, though Cully et al. (2014) categorized disturbances using terms similar to the name of threats used to calculate AHP in

Section 3.3, a refined algorithm for adjusting the AHP values based on the categorized and observed disturbances of Cully et al. (2014), needs to be developed and tested.

If a range wide analysis of image data compared to the NLCD 2011 data set used to calculate AHP bears out the significant underestimation of fragmentation of habitat as observed by Cully et al. (2014), the value of Population Capacity could drop by two orders of magnitude, bringing its value much closer to the threshold of viability expressed in the inequality of Equation 8.

3.7.2 Rescuability and Local Computation of Metrics

Population Capacity and PC Index both represent range-wide metrics. However, because the calculation methods for both metrics are non-recursive, and impacted areas are restricted to a buffer of a few times the migration distance *L* of the area of change in AHP, resulting changes to the metrics is inherently local. Being able to estimate the change in population fragmentation when a local change is made to the landscape would greatly simplify the incorporation of either of these metrics into the Desert Tortoise SDSS.

Both the PC Index and Population Capacity offer approaches to calculating the change in the range-wide value without recalculating over the entire range.

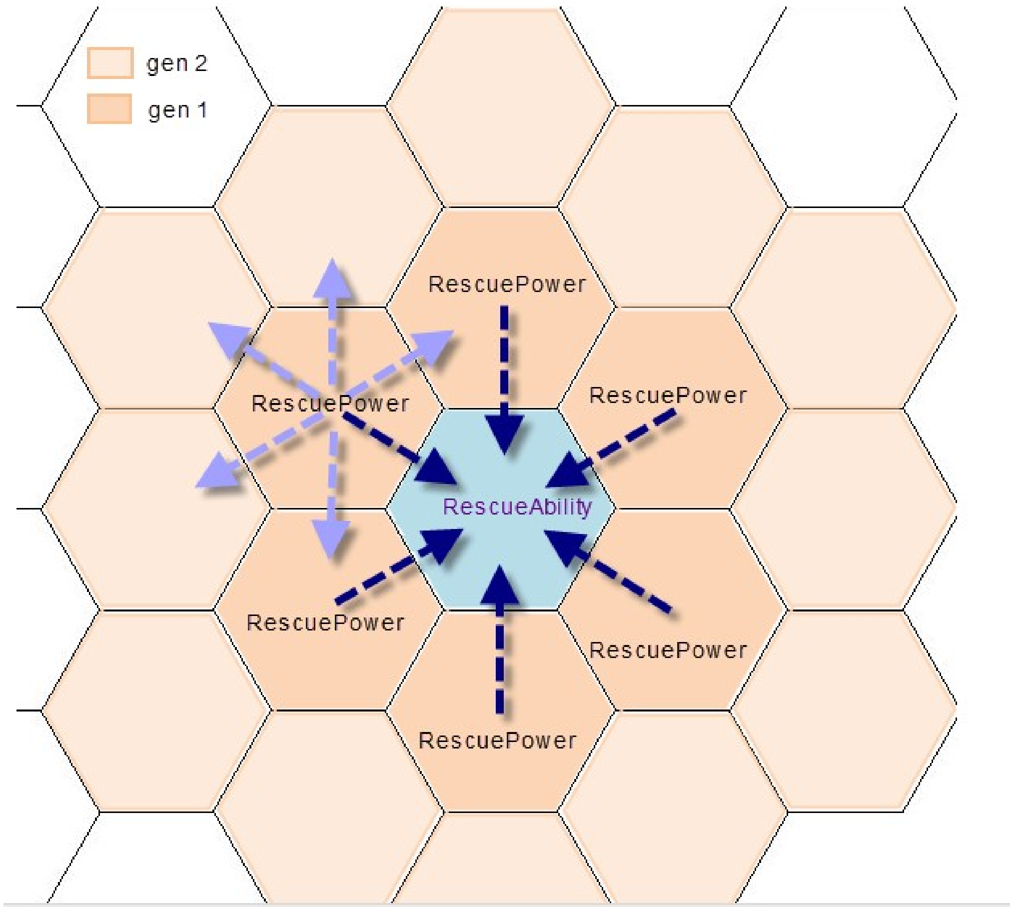
3.7.2.1 Local Computation of Changes in PC Index Based on Local Changes in the Landscape

In parallel with investigations into range-wide metrics, the project team developed a metric intended to characterize how well local populations could recover from localized disasters. This alternate metric for population fragmentation was called *rescuability (resilience)*, which is the likelihood of a particular hexagonal cell (tortoise patch) being "rescued" from extinction by the combined recolonization potential of all other cells in the range (Figure 31).

Once more the AHP was used as an indicator of the population likely to be in a cell, and it was assumed that juveniles and adults choosing to leave a hexagonal cell could exit randomly from any of its six edges. In this case, the likelihood that a cell is rescued by the population from its neighboring cells is the sum of each of their AHP, divided by 6. However, if the original cell has poor habitat, this diminishes the ability of individuals from its nearest neighbors to travel into and survive in that cell. The project partners define the *rescuability* of a cell *k* as its own habitat value times the sum of its nearest neighbors AHP values, divided by 6:

$$\boldsymbol{R_i = (\textstyle\sum_{j=1}^{6} AHP_j/6) * AHP_i} \qquad \textbf{\textit{Eq} 16a}$$

Figure 31: Rescuability (Resilience) of a Habitat Patch



The resilience or "rescuability" of any given habitat patch depends on both its own AHP and that of its *six* neighbors.

Source: Desert Tortoise SDSS

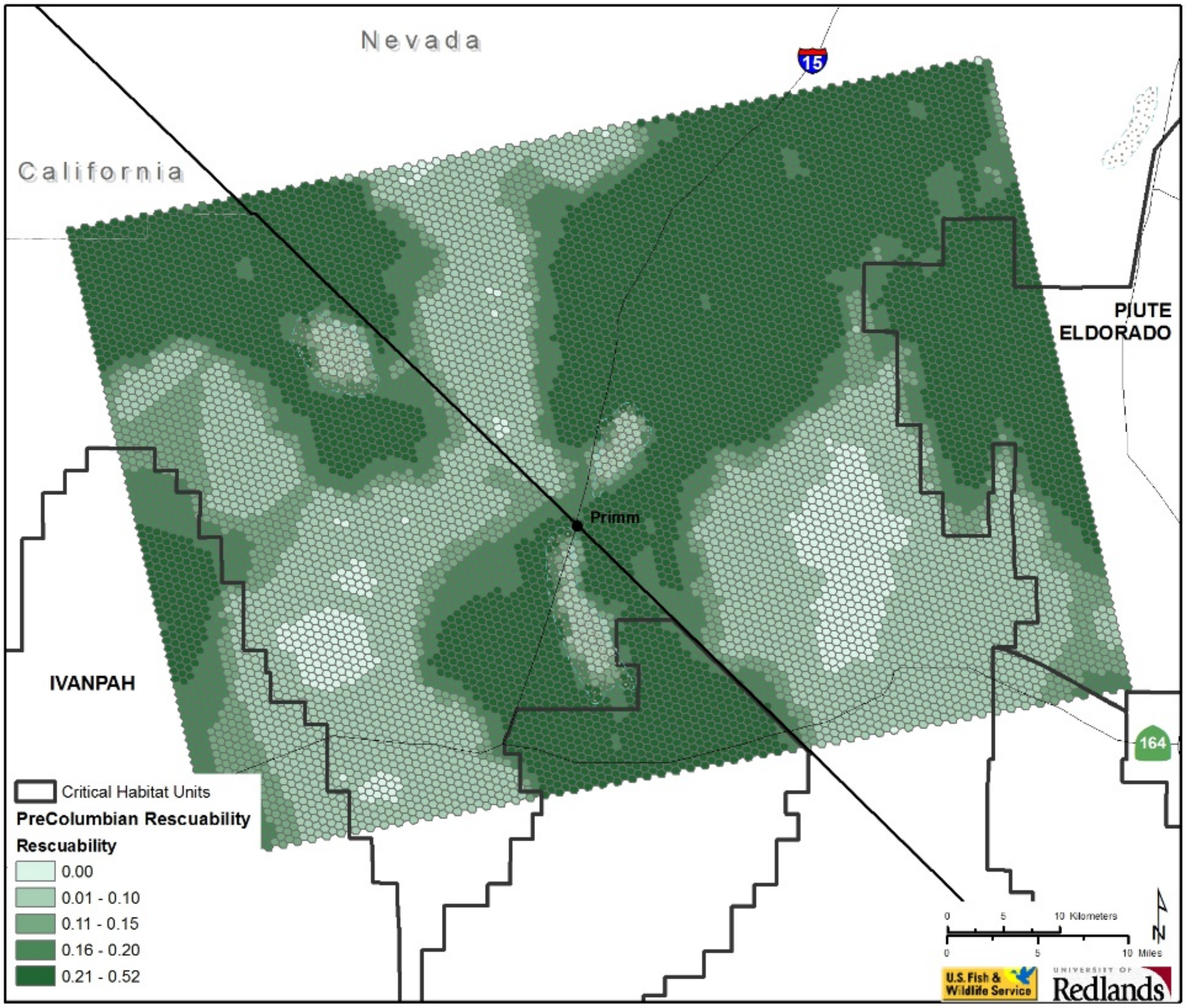
If all travel is limited to nearest neighbor territories, and using the expression for PC*Index for hexagonal tiling in Equation 10, it is straightforward to show that the PC Index is directly related to the range wide average rescuability.

$$\boldsymbol{PC^* = \frac{1}{N}E\left(AHP^2\right) + \ E(Rescuability) * \left(\frac{6}{N}\right)}$$

$$\boldsymbol{for\ nearest\ neighbour\ migration\ only \qquad Eq\ 17a}$$

The project partners calculated the rescuability for all territories in a smaller study area within the Ivanpah Valley study area (to avoid edge effects). Rescuability was calculated for the three solar scenarios described previously: (1) Pre-Columbian, (2) Post-Brightsource ISEGS Baseline, and (3) with the footprints of ISEGS, Silver State, and First Solar Stateline (3 Solar Scenario) (Figures 32 – 34).

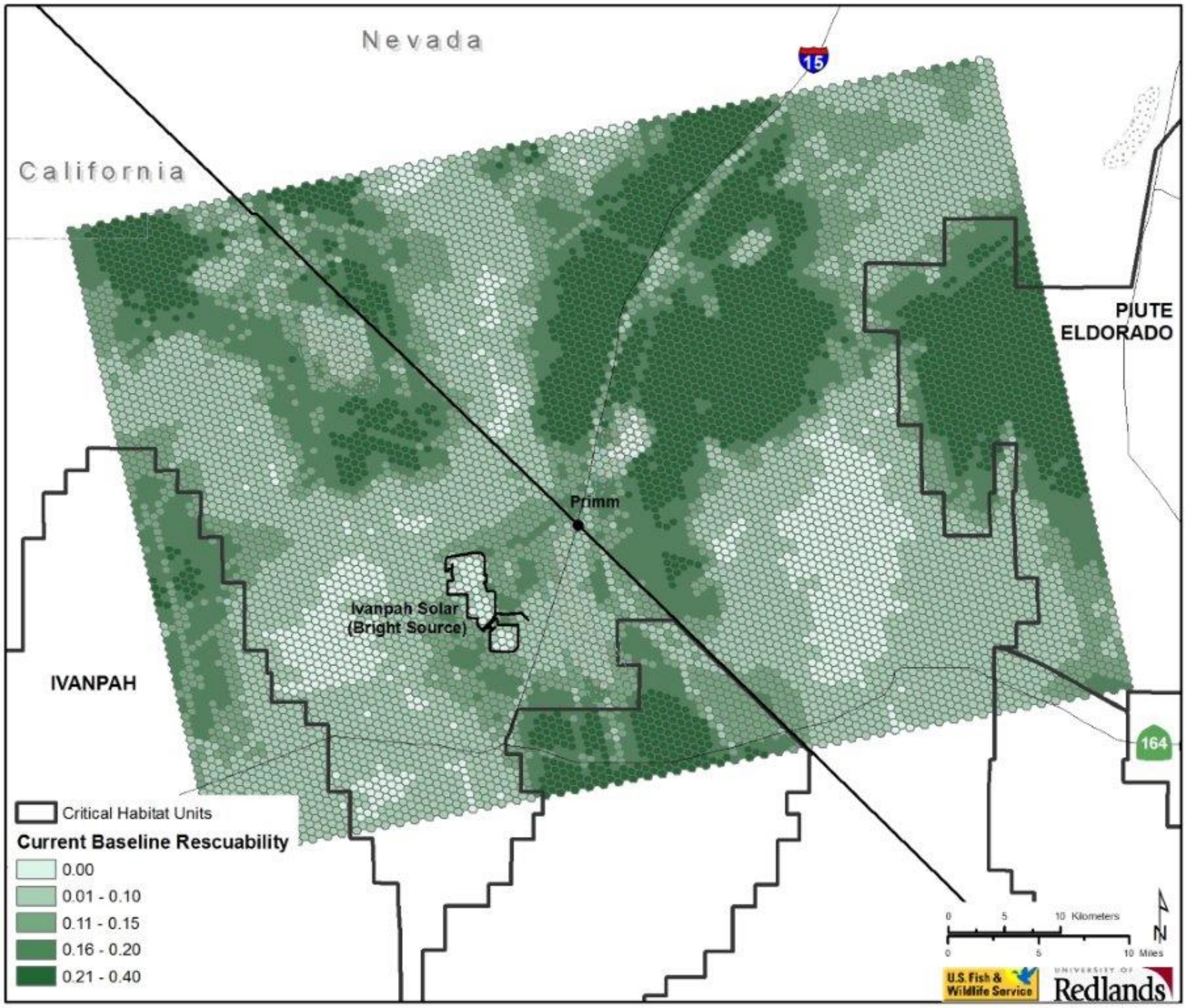
Figure 32: Rescuability (Resilience) Map for the Pre-Columbian Era



Results of calculation of *rescuability (resilience)* of habitat patches for desert tortoise in the Pre-Columbian era. Lighter green are habitat patches with less resilience or probability of rescue, by migrating desert tortoises. Also shown are the outlines of the two nearest desert tortoise critical habitat unit areas: Ivanpah and Piute-El Dorado. Note the two corridors running North-South in the Ivanpah Valley on both sides of Ivanpah Dry Lake (the very low AHP area directly south of the town of Primm).

Source: Desert Tortoise SDSS

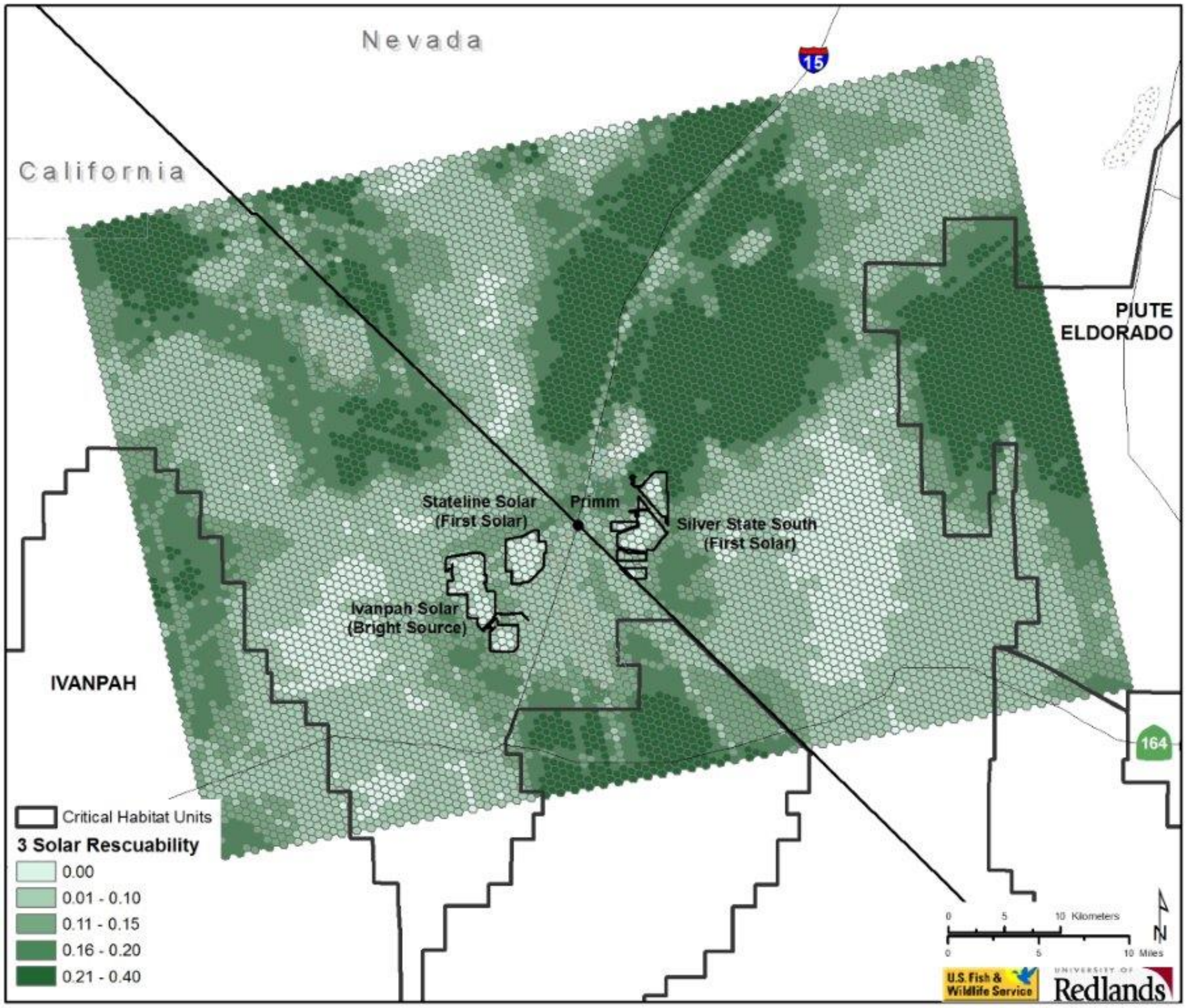
Figure 33: Rescuability Map for the Post-Brightsource ISEGS Baseline Scenario



Results of calculation of rescuability (resilience) of habitat patches for desert tortoise under the post-Brightsource ISEGS scenario, which includes the ISEGS project footprint (small polygons outlined in black). Lighter green are habitat patches with less resilience, or probability of rescue, by migrating desert tortoises. The insertion of the BrightSource ISEGS plant, along with other existing developments such as the freeway, greatly reduces rescuability in the corridor to the west of the Ivanpah Dry Lake. For the population to live and migrate over generations through the western corridor, tortoises now need to dwell in home ranges whose rescuability is as low as if they were on the playa itself.

Source: Desert Tortoise SDSS

Figure 34: Rescuability Map for the 3 Solar Scenario



Results of calculation of rescuability of habitat patches for desert tortoise including both ISEGS and the addition of projected Stateline Solar (CA) and Silver State South (NV) footprints (smaller polygons outlined in black). Lighter green are habitat patches with less resilience, or probability of rescue, by migrating desert tortoises. The addition of these two solar energy developments would greatly reduce rescuability in the remaining eastern corridor around the Ivanpah Dry Lake.

Source: Desert Tortoise SDS

As the captions to Figures 32-34 state, in the Pre-Columbian scenario, the two North-South corridors between the mountain ranges and the Ivanpah Dry Lake (a terminal basin) south of today's town of Primm (see Figure 22) were made up of uninterrupted highly rescuable territories. Siting and completion of the ISEGS project degraded rescuability in the western corridor, and construction of Stateline Solar would further degrade the habitat in the western corridor, but some better habitat remains to its North East. The Silver State project would degrade the remaining eastern corridor, though again leave a corridor to the east of its site where home ranges would be somewhat more rescuable compared to the playa.

Rescuability does not provide an independent metric, as it is intrinsically linked to PC* Index. This can be made explicit by generalizing the thought experiment of Equation 6.

To do so, the team introduced a general definition of rescuability, building in Equation 16a:

$$R_i = AHP_i * \frac{\sum_{i \neq j}\left(AHP_j * exp - \left(\sum_{l=0}^{n} \left(\frac{ED_l}{AHP_l}\right)/L\right)\right)}{\left(\sum_{i \neq j}\left(exp - \left(\sum_{l=0}^{n} (ED_l)/L\right)\right)\right)} \qquad \textbf{\textit{Eq 16b}}$$

The denominator is the resilience or rescuability in a landscape with perfect habitat everywhere. It is independent of any individual territory, but is dependent on the size of the hexagon tiles and the migration distance *L*. It represents the equivalent number of territories surrounding the focus territory that would rescue that territory with probability of 1. This equivalent neighbor number, N_{en} is 596 (when rounded) for the 30.04 hectare tiling and 10km migration radius used in this analysis.

The rescuability of a territory can then be written as the ratio of equivalent rescue territories in the imperfect landscape compared to a landscape of perfect habitat everywhere (Eq 16c). Its value always falls between 0 and 1, rising to 1 for a territory surrounded by excellent habitat.

$$R_i = AHP_i * \frac{\sum_{i \neq j}\left(AHP_j * exp - \left(\sum_{l=0}^{n} \left(\frac{ED_l}{AHP_l}\right)/L\right)\right)}{N_{en}} = \frac{\sum_{i \neq j} \widetilde{M}_{ij}}{N_{en}} \qquad \textbf{\textit{Eq 16c}}$$

Using Equation 12, PC* Index can then be expressed in terms of the expected value of rescuability range-wide:

$$PC^* = \frac{1}{N} E\left(AHP^2\right) + E(Rescuability) * \left(\frac{N_{en}}{N}\right) \qquad \textbf{\textit{Eq 17b}}$$

If the range of a species is expanded in a similar landscape, the variance in the AHP and the expected value of rescuability will not change by much, so PC* Index will fall as *1/N*, as *N* increases, as anticipated in the previous section.

The first term in Equation 17a that involves the variance in AHP corresponds to the Intra-patch connectivity of Saura and Rubio (2010). For the Ivanpah Valley study area, that first term only contributes 0.0001 to PC* Index for the full study area. The second term, the Interpatch connectivity of Suara and Rubio, contributes 0.00323 to PC* Index, or 99.7% of its value. Hence the straight path PC Index in a tiled landscape is essentially the average rescuability scaled by the factor $\frac{N_{en}}{N} = 595.286/33{,}282$ = 0.01792. This latter factor explains the small value of the PC Index for a tiled landscape in which the study area is much larger than the effective radius of rescue territories.

What rescuability does provide is a direct measure of rescue potential for each territory in an imperfect landscape, along with a strong visual representation and a local method to calculate changes in PC* Index. If a local catastrophe befalls a cluster of territories, the change in PC* Index for the entire range can be estimated with good accuracy by calculating the change in rescuability of territories within a radius of 5**L* = 50km of the source change. That is still a large fraction of all the nodes in the Ivanpah Valley study area, but represents a much smaller set compared to the full range (N~500,000 hexagon territories).

3.7.2.2 Local Computation of Population Capacity

The principal eigenvalue is a global property of a matrix. However if the leading eigenvector can be calculated, Hanski and Ovaskainen (2000) provide a formula (Equation 6 from that paper) to calculate the relative contribution of each territory based on that eigenvector. If x_i is the i^{th} element of the (normalized) leading eigenvector, then the contribution $\Delta\lambda_{PC}^{i}$ of the i^{th} territory to Population Capacity λ_{PC} is given by:

$$\Delta\lambda_{PC}^{i} = \boldsymbol{R_i}^2 * \frac{{x_i}^2}{\lambda_{PC}} \qquad Eq\ 18$$

This would have a positive value when adding a new or improving an existing territory, and a negative value if the territory is being removed or degraded. If the current value for Population Capacity is known, Equation 18 provides a local calculation to adjust its overall value. The same Scientific Python (SciPy) implementation of the Lanczos Algorithm that calculates $\boldsymbol{\lambda_{PC}}$ also efficiently calculates the leading eigenvector corresponding to that eigenvalue. For the full Ivanpah Valley study area, the entire calculation takes just 90 seconds.

Equation 18 is the means to calculate the change in population fragmentation for any improvement in AHP. Where a road had overlapped more than 20% of a home range hexagon so that AHP in that home range was set to 0, adding a culvert underneath the road will restore the original average AHP of that home range. Habitat restoration always at least partially raises the AHP over the restoration area. In both cases, the rescuability R_i can be recalculated locally and will increase. Equation 18 will provide an estimate to the increase in overall population connectivity. Whether that is significant at the corridor or range scale remains to be seen.

3.8 Integration With the Desert Tortoise SDSS

The ultimate objective of this research was to replace the initial model that computed the effect of destroyed or degraded habitat on population fragmentation in the Desert Tortoise SDSS. Results for both metrics within the Ivanpah Valley study area do suggest that these metrics would provide a more accurate representation of the change in landscape fragmentation than the current model used, which only looks at the size of habitat lost, and whether or not it is in a corridor.

Based on the computational exploration of the last section, both PC* Index and Population Capacity have local algorithms that would allow real time updates over range wide index values in response to a change in the landscape.

3.8.1 Calculating Population Fragmentation Metrics Range-Wide

The team did not calculate either population fragmentation metric for the full desert tortoise range. Hexagon coverages were generated for the full range, requiring 500k-550k hexagons depending on the extent of buffering around the borders. A scheme for calculating all non-zero Euclidean and effective distances in tranches of 100K hexagons was tested. However all focus was on the Population Capacity eigenvalue calculation. The Python script that accesses and implements the SciPy wrapper of the Lanczos algorithm first creates an *NxN* matrix of 0's, then overwrites non-zero elements with $\widehat{\boldsymbol{M}}_{ij}$ values that from a SQL database, where they had been calculated and stored. For the Ivanpah Valley study area, creating the matrix took the most time (50-60 seconds), but did not require much extra memory or CPU.

In 64-bit SciPy, the 33k territories (hexagons), produced 1 *billion* territory pairs which at 8 bytes per entry, would require about 8 gigabytes of memory. In fact, on the main calculation server used for this project, the actual eigenvalue calculation would max out all 8 CPUs, but only require 7-8 gigabytes of the 64 gigabyte memory available on the machine. Creating the matrix in Python turned out to be an insurmountable roadblock. The largest matrix created was 100k x 100k, and any matrices greater than that caused an "out of memory" error.

The team experimented with a number of approaches to reduce the number of cells (remove hexagons with AHP less than a threshold) or adjust system parameters, to no avail.

The local computation based on Equation 18 for Population Capacity requires the leading eigenvector from the matrix of the entire range, and so does not even provide a way to calculate the relative impact of a local change.

The team had started to consider methods that calculated Population Capacity for portions of the range, in order to then aggregate into a range-wide value. However, no satisfactory approach was reached by the close of this project.

PC* Index can be calculated range-wide. Although its computation was presented in terms of $\widehat{\boldsymbol{M}}_{ij}$ (see Equation 12), PC* Index involves only a sum over matrix elements, and their values are stored in Microsoft SQL, where up to a trillion values can be summed without issues. Indeed the rescuability for all territories in the range can be calculated and stored and used to calculate both a range-wide PC* Index (via Equation 17b) or local impacts (via Equation 18).

Focused on the goal of using Population Capacity to validate population viability, the team did not execute the calculation of PC* Index range-wide in this project.

3.8.2 Integrating Metapopulation Metrics in the Desert Tortoise SDSS

This final section considers future approaches to successfully calculating Population Capacity. There are no impediments to calculating PC* Index for the full range.

Assuming one of the metrics is available range-wide, and locally, the team had two methods in mind to integrate these metrics with the main Desert Tortoise SDSS. The simplest is to continue with the weighted sum approach that underlies the current computational model for the system. The old, area-in-a-corridor estimate is replaced by the new metric. If the local computational method for the new metric is employed, the calculation of the contribution of the local impact to overall aggregate threats and risk to the population is exactly as before.

In the last section of Chapter 5, a new approach to better model the interplay between habitat and demographic change is outlined. There the holistic, range-wide aspects of Population Capacity metrics would come into play.

3.9 Discussion

In investigating new approaches to quantitatively assess landscape fragmentation and how to calculate its impact on the population, the team investigated a population diffusion model (FRAGGLE), but ultimately rejected this model because it was (a) sensitive to many parameters that are not well known; and (b) computationally too demanding. The team then developed and implemented two metapopulation-based metrics: a straight-line, tiled implementation of the *PC Index*, and a new *Population Capacity*. Both metrics proved sensitive to topographical changes in the landscape, improving on the current computational model for population fragmentation. Both metrics have local calculation algorithms available to them, and both proved computationally efficient in the Ivanpah Valley Study area, which covers 6.4% of the range.

Table 14 presents a comparison of the merits of the three population fragmentation metrics explored as part of this project.

Table 14: Summary Comparison of Population Fragmentation Metrics

Metric	Benefits	Challenges
Probability of Connection Index (PC Index)	Fast to calculate (summation) if not least cost path. Very scalable. Change in local habitat can be calculated locally.	Leaves unanswered the question of when is a change critical: what is the threshold for population collapse?
Population Capacity, λ_P.	Directly related to a threshold for viability: $\lambda_{PC} > \tau = \frac{(1-s)}{b}$ Local changes require global recalculation, but it can be fast.	What do values of 200-300 mean for Population Capacity? How do those values relate to the recolonization potential *(1-s)/b?* Calculating λ_{PC} range wide
Rescuability	Directly and visually captures concept of rescue and resilience. Local change computed locally. Appears to suggest when a linkage is lost	How to quantify when a linkage is lost? Not (yet) related to any test for viability

PC Indices are well accepted in the literature. The straight-line, tiled implementation investigated in this study is computationally straightforward, and scales well.

Population Capacity is a new connectivity construct, whose estimated values for the Ivanpah Valley Study area would suggest that the desert tortoises easily meet the threshold for viability. In the Revised Recovery Plan for the Desert Tortoise (USFWS, 2011) the authors note that the population levels are below required levels for sustainability and that the available evidence suggests the population continues to decline in most areas of the range, especially in its western portion. New observations of trends in population presented in Chapter 5 further support this claim (see Fig 5.1). Those estimated values of the metric therefore fail to signal the observed state of the population within the study area. This is disappointing when one of the objectives of this research was to develop a metric capable of signaling when proposed additional landscape fragmentation results in a habitat incapable of sustaining the population.

However refinements in the estimation of AHP may well change that situation. It faces computational challenges when scaled to the full desert tortoise range. However, unlike PC Index, it has the potential to link habitat and demographic rates, potentially providing a threshold for viability. In Hanski and Ovaskainen (2002) the authors not only posit a viability test for the entire range, but on choosing any patch, they were able to use their metapopulation capacity approach to calculate the minimum disc of habitat surrounding that patch required for viability. If Population Capacity can be applied in the same way, a more regional analysis of population viability for the desert tortoise may be possible.

Moving forward, the computational issues with Population Capacity can be met. Larger, faster computers and clusters of computers are available with greater memory and processing power. Calculating principal eigenvalues is critical for image processing, large scale ranking problems, and natural language programming, to name but a few applications, so more efficient algorithms are likely to appear in the near future. Meanwhile the current SciPy algorithm wrapper has a mode that appears not to require the matrix construct to be fully loaded into memory; it can load each matrix element as needed from a function or database. In addition, by eliminating territories with low AHP value, is seems likely that the number of territories that need be included for range-wide coverage can be greatly reduced.

In summary, though the team did not achieve a fully integrated landscape fragmentation metric within the timeline of this project, they believe that the new Population Capacity metric has the potential to be used for population fragmentation impacts analysis, setting thresholds for population viability and supporting the design of recovery actions that help restore habitat within the range.

CHAPTER 4: System Testing: Solar Impact and Mitigation Calculations and Uncertainty Analysis

4.1 Selection of Three Solar Energy Projects for System Testing

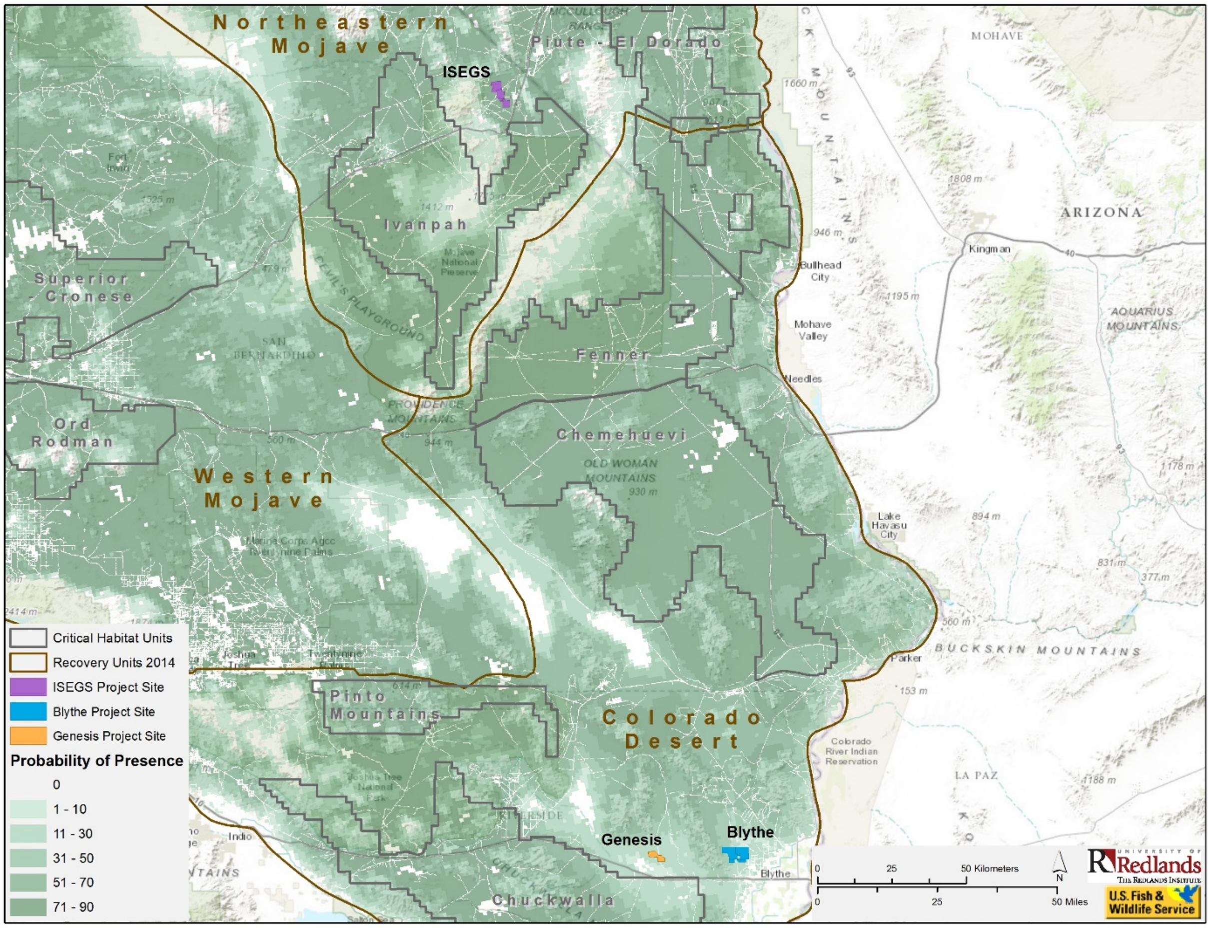
An objective of this project was to test the effectiveness of the Desert Tortoise SDSS modeling engine and system performance through quantitative runs of the system on various solar energy projects. A conversation between Energy Commission staff, Energy Commission lawyers, and the project team took place on 9/21/2012 to discuss how best to undertake testing system calculations, given concern about how the preliminary test information might be used in decision-making. The group decided that the test calculations should be run for existing solar energy projects only, under several different system improvement scenarios. This would provide time for the Siting and Legal staff to develop guidance for how to use information from the system in evaluating the effects of proposed projects. It was decided to test system calculations on the Ivanpah Solar Energy Generating System (ISEGS) project, the Genesis Solar Energy project, and the Blythe Solar Power project (Figure 35).

4.2 Sequential Runs With Incremental System Improvements

The project team tested changes to the workflow, system interfaces, input data and underlying models by running the system for the three study solar energy projects and their associated mitigation packages. The first step was calculating baseline results for each project using the system iteration from the end of the previous Energy Commission project, and establishing the baseline workflow and system performance. In the course of this project, the team identified five changes to the system model that substantially changed outputs compared to the baseline: (1) weights normalization and double counting of recovery action effects, (2) removal of threats and recovery actions types that played no significant role, (3) changes in spatial computation methods, (4) replacement of potential conversion by a formal submodel for potential urbanization and (5) incorporation of an enhanced spatial model for population fragmentation. For each major change to the system model, the project team re-ran the calculations for the unchanged ISEGS study proposal, whose outputs they had first calculated using the system developed in the previous PIER proposal.

As discussed in Chapter 3, the team was unable to incorporate the new population fragmentation model into the final 2014 Desert Tortoise SDSS iteration. For brevity, the above model changes (1)-(4) were combined, and are described in this chapter as the 2014 SDSS model. For the ISEGS proposal, the project team provided aggregate results and spatial distributions of new outcomes and differences between the 2011 and 2014 versions of the system. For the other two solar energy projects, the results based on the 2014 version are provided in this chapter.

Figure 35: Three Study Solar Energy Projects Used in System Testing



The three proposed solar energy development projects used in Desert Tortoise SDSS system testing are distributed across the Western Mojave.

Source: Desert Tortoise SDSS

4.3 ISEGS Solar Energy Project Calculations: Comparison of Calculations With 2011 and 2014 System

4.3.1 System Calculations for ISEGS Study Project

In 2011, the project team received data on an early design proposal for a solar energy development in the Ivanpah Valley area. Some management actions for mitigation were supplied to the team by the Energy Commission and BLM, and these were augmented twice in the following months. This design analyzed for the ISEGS concentrating solar power (power tower) station was an early version; the ISEGS project that was ultimately built in the Ivanpah valley, north of Interstate 15 just west of the California-Nevada border (see Figure 35 above) was significantly modified. The project team used the August 2011 version of the Desert Tortoise SDSS to create a quantitative report on both the expected impacts of the proposed 2011 ISEGS project design and the estimated benefit from proposed mitigation actions (Murphy et al, 2013: Appendix F). Those results are summarized below. The team then ran the same analysis against the 2011 ISEGS project design and mitigation package data using the 2014 version of the SDSS. Comparing the results from the two runs, the team was able to verify the outputs of the updated system, and the implications of the data, model (conceptual and spatial) and architecture changes made as part of this project (Chapter 2).

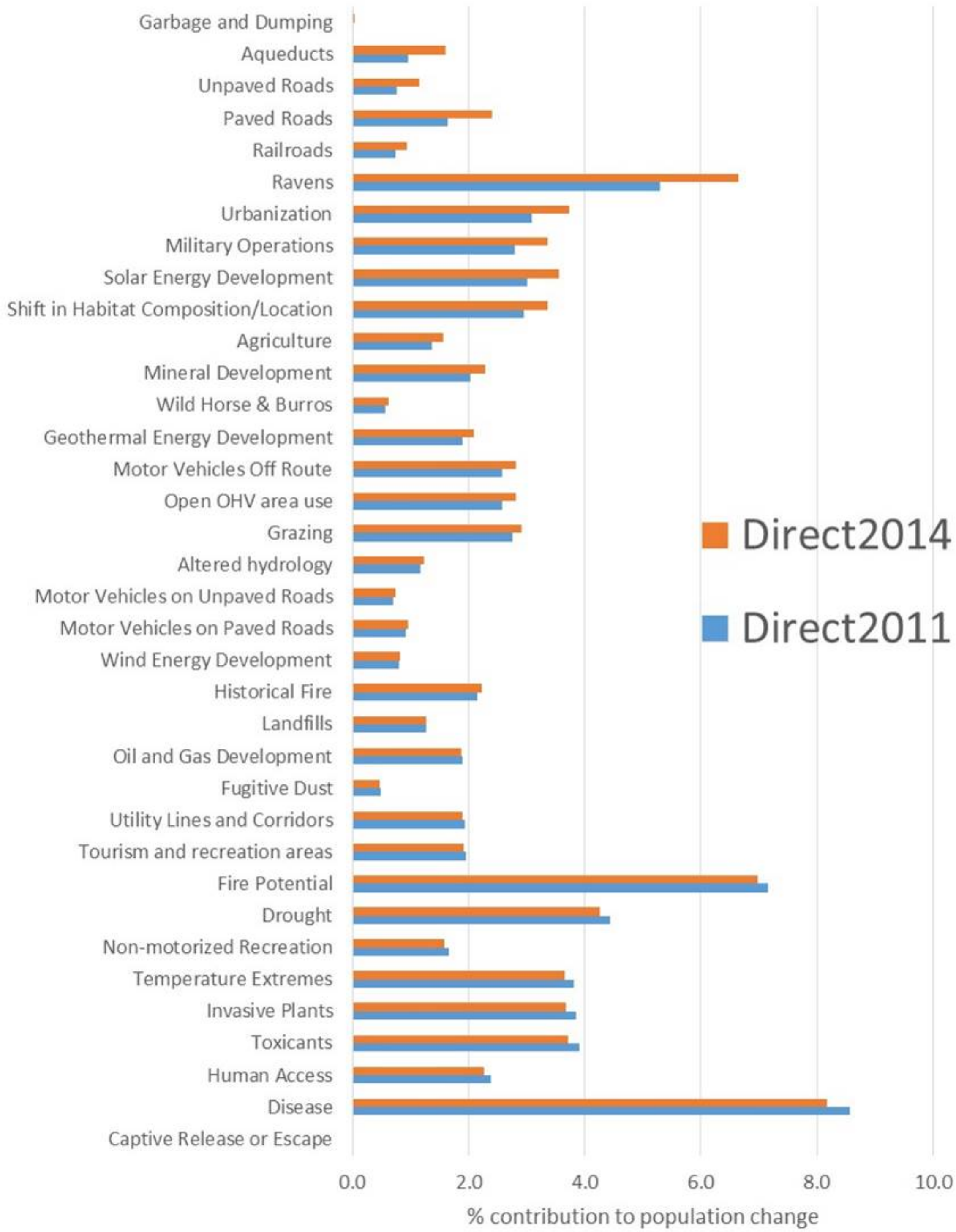
4.3.2 Evolution in the Conceptual Model between 2011 and 2014

Based on a new round of consultations with domain experts, new literature and discussions within the DTRO, the entities, connections, and weights of the desert tortoise conceptual model underwent considerable refinement in the period between the first set of ISEGS calculations in Fall 2011 and the updated calculations performed in Spring 2014 as part of this project. These led to new values in the conceptual model for the aspatial contribution of (a) threats to population change, and (b) recovery action types to risk reduction.

4.3.2.1 Changes in the Conceptual Model Related to Threats

In the 2014 conceptual model, a number of threats, including Climatic Variation, OHV Events, and Unknown Disease Contributors were removed entirely. The threat of Surface Disturbance was split into Active Surface Disturbance and Former Surface Disturbance, to better represent the effects to the tortoise. The threat of Free Roaming Dogs was merged into Coyote and Feral Dogs, so that former threats defined as Predators were now fully represented by two individual threats: Coyote and Feral Dogs, and Ravens. As a result of these changes, the direct weight increased for most other surviving threats in the model, since all weights in the model are relative to one another (Figure 36). The effects of these changes were evident in the calculations for the study solar project mitigation packages. In particular, for the ISEGS mitigation packages, the direct weights of the threats of Paved Roads, Ravens and Urbanization increased by 46%, 25% and 21% respectively.

Figure 36: Changes in Values for Threats in the 2011 vs 2014 Conceptual Models at ISEGS



Comparison of direct weights of threats that exist in both the 2011 and 2014 system conceptual models, due to changes in the weights, entities and connections in the models.

Source: Desert Tortoise SDSS

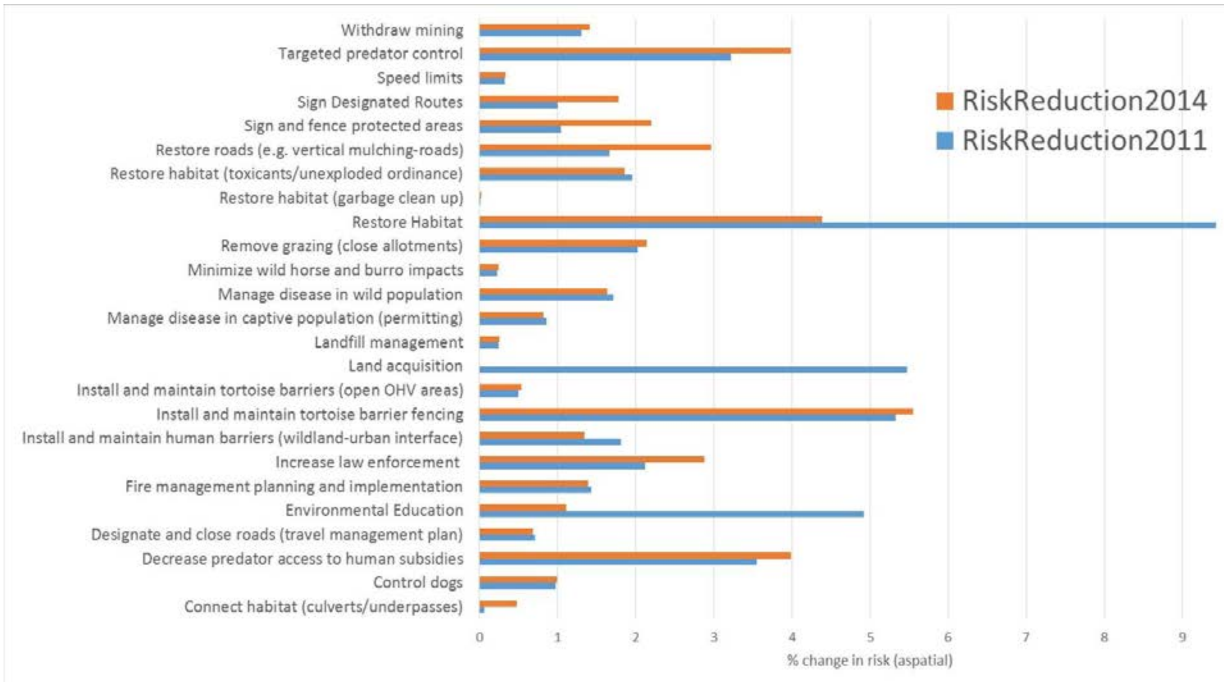
4.3.2.2 Changes in the Conceptual Model Related to Recovery Actions

The project team also made significant improvements to recovery action type weights. The weight for the recovery action type Environmental Education dropped by a factor of 5, reflecting the new understanding that there are five types of environmental education actions, and each is effective in different ways. The value for Restore Habitat was decreased upon realizing that the 2011 conceptual model essentially double-counted the effectiveness of all recovery actions that improve the habitat, because they contributed both to (a) suppressing the direct contributions of threats to the stress of Habitat Loss; and (b) through suppressing the contributions of the threat of Surface Disturbance to which those same threats contributed. In addition the team concluded that habitat restoration is generally conducted on former, rather than current, threats (e.g. habitat restoration is not conducted on current agriculture; habitat restoration is conducted on fallow or former agricultural fields). Therefore, Restore Habitat was disconnected from most current threats, except those that Restore Habitat can actually act upon (e.g., Invasive Plants). Restore Habitat remained connected to former threats in the conceptual model (e.g., Historical Fire and Motor Vehicles Off Route).

Two recovery action types were removed: one because the threat (Restrict OHV events) is believed to be negligible, the other, Install and Maintain Human barriers (preserves), because it duplicated the recovery action type Sign and Fence Protected Areas.

Most effectiveness scores for recovery action types that were part of the ISEGS mitigation package were similar in the 2011 and 2014 model runs. However, (aspatial) risk reduction from the recovery action type Increase Law Enforcement increased by about 36%, and the action type, Install and Maintain Human Barriers (wildland-urban interface) decreased by 26%. These changes were due to (1) changes in contributions to population factors of the main stresses on which they act; and (2) correction of weights normalization errors in the 2011 version of the model. The recovery action type of Land Acquisition was improved to only act through suppressing the threat of potential urbanization, so that it would reduce future risk, rather than current risk to the population. All of these changes are summarized in Figure 37.

Figure 37: Difference in Risk Reduction for Recovery Action Types in the 2011 vs 2014 Conceptual Models at ISEGS

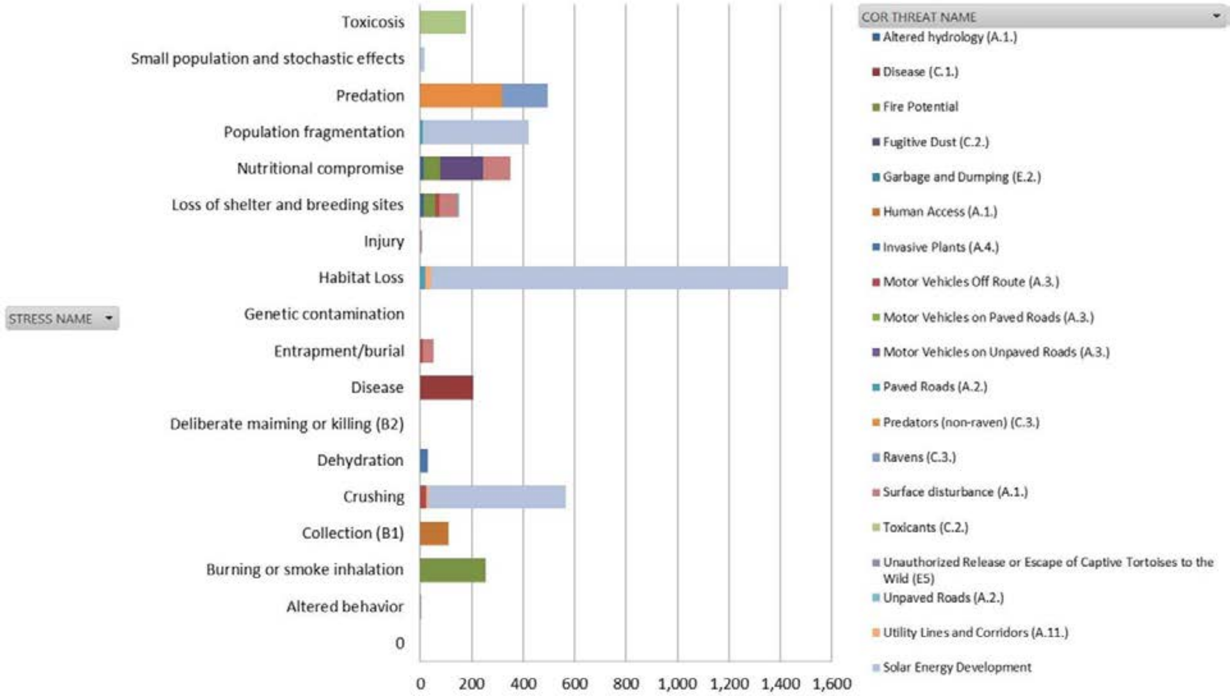


Source: Desert Tortoise SDSS

4.3.3 ISEGS Project Impact Calculations: 2011 vs. 2014

Using the 2011 Desert Tortoise SDSS, which at that time involved manually running complex scripts, then extracting the results and graphing them in Excel, the project team estimated the increase in risk to the population due to placing the project on the landscape on a scale of risk units. The 2011 SDSS estimated an increase in risk to the tortoise population of 4,725 risk units (Figure 38).

Figure 38: Increased Risk to Population From Implementing ISEGS 2011 Design (2011 System Calculations)

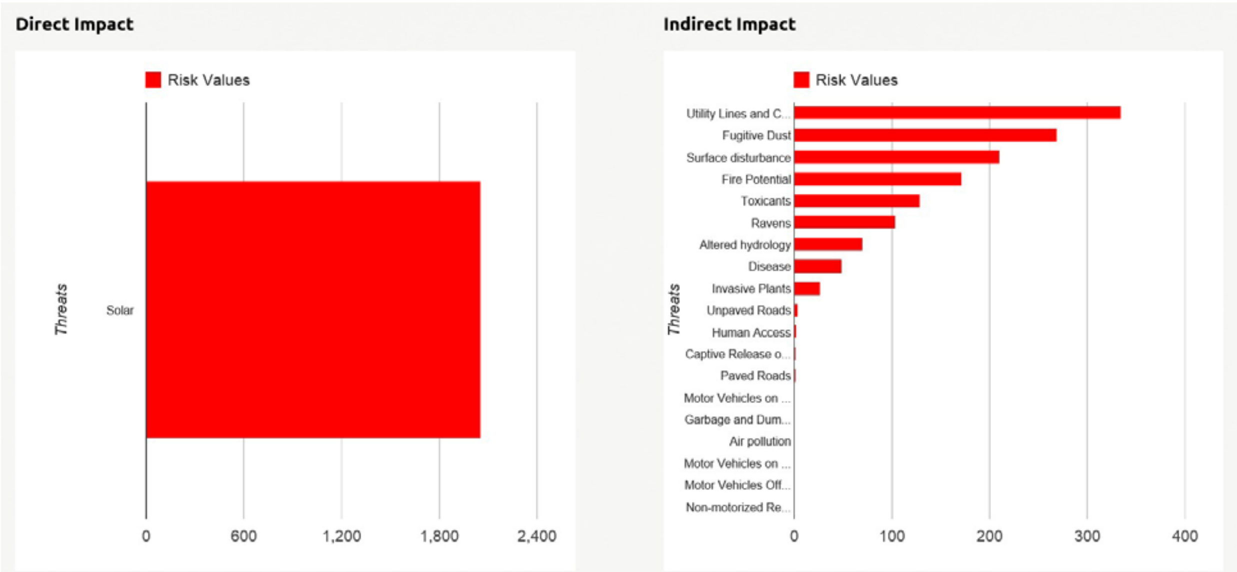


Estimated increase in risk to the population, if the ISEGS 2011 design were implemented on the proposed site in the Mojave Desert, using the 2011 system version.

Source: Desert Tortoise SDSS (2011 System version)

The project partners re-ran impact calculations for the same 2011 ISEGS design, this time using the 2014 conceptual model, threats data and SDSS engine version (Figure 39). The 2014 SDSS estimated an increase of 3,430 risk units, 2,055 (60%) as a direct result of placing the project and its supporting features on the landscape, and 1,375 (40%) due to indirect effects.

Figure 39: Estimated Increase in Risk to Tortoise Population From ISEGS Project Direct and Indirect Impacts (2014 Calculations)

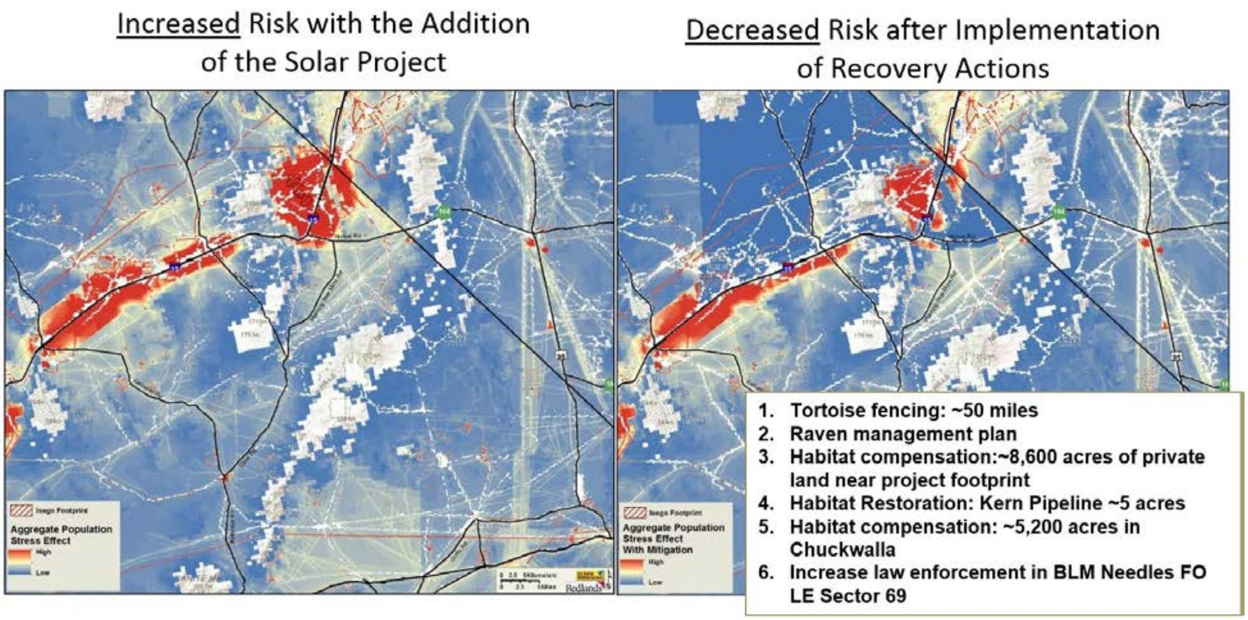


2014 system estimates of the direct impacts from the threat of solar energy development and impacts from the indirect threats that are increased by placing ISEGS on the landscape. The horizontal scale represents risk units.

Source: Desert Tortoise SDSS (2011 System version)

The project team also mapped the change in overall risk across the landscape. In 2011, these maps were manually created in ArcMap (Figure 40). In 2014, these maps were generated in the Solar Project Impact and Mitigation Online Tool (Figure 41).

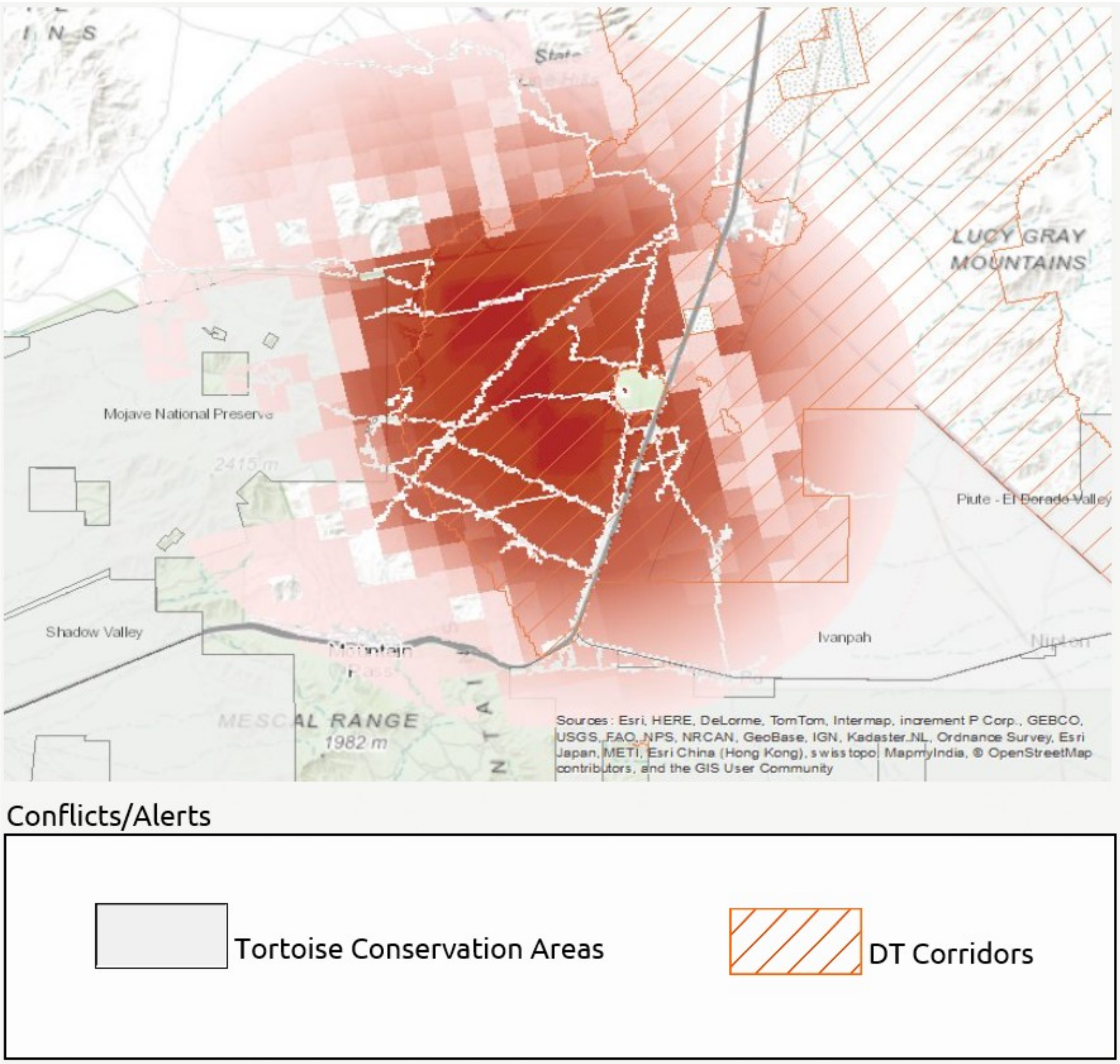
Figure 40: Spatial Distribution of Overall Risk to the Tortoise Population at ISEGS (2011 System Calculations)



Spatial distribution of change in overall risk to the tortoise population, based on the 2011 system version. The proposed 2011 ISEGS project design is located in the central red area.

Source: Desert Tortoise SDSS (2011 System version)

Figure 41: Spatial Distribution of Overall Risk to the Tortoise Population Resulting From ISEGS (2014 System Calculations)



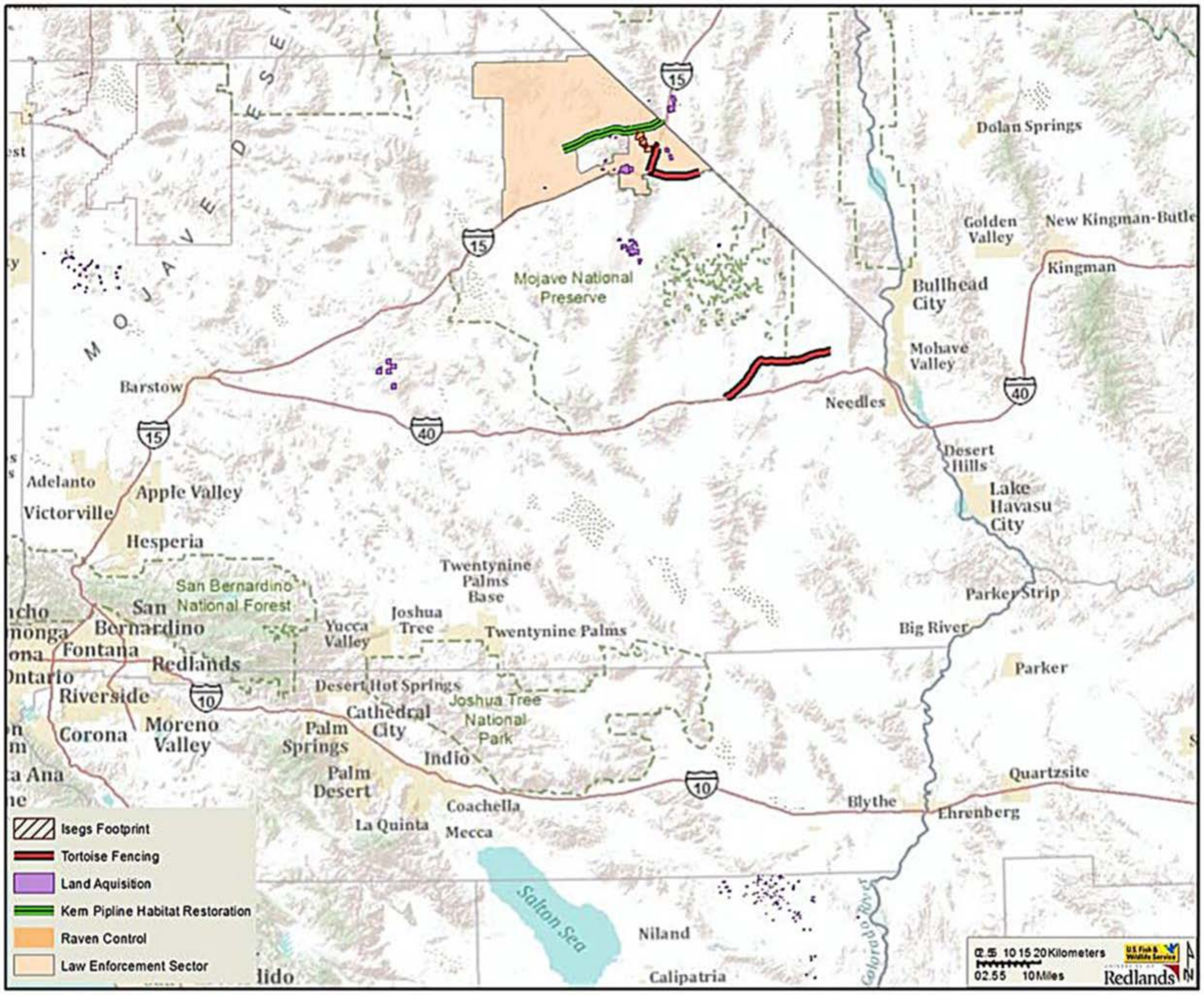
2014 spatial distribution of the increase in risk to the tortoise were the proposed 2011 design of the ISEGS project placed on the landscape. The higher the increase in risk, the deeper the hue of red.

Source: Desert Tortoise SDSS (2011 System version)

4.3.4 ISEGS Project Mitigation Calculations: 2011 and 2014

The same set of recovery actions was used in the 2011 and 2014 SDSS estimation of the effectiveness of mitigation packages for ISEGS. This set of actions included installing tortoise barrier fencing, habitat restoration, land acquisition, raven management actions, and an increase in law enforcement (Figure 42).

Figure 42: Map of Proposed Mitigation Actions for ISEGS 2011 Design



The footprint of ISEGS (three adjacent polygons in the northern middle of the map) and proposed desert tortoise mitigation actions.

Source: Desert Tortoise SDSS

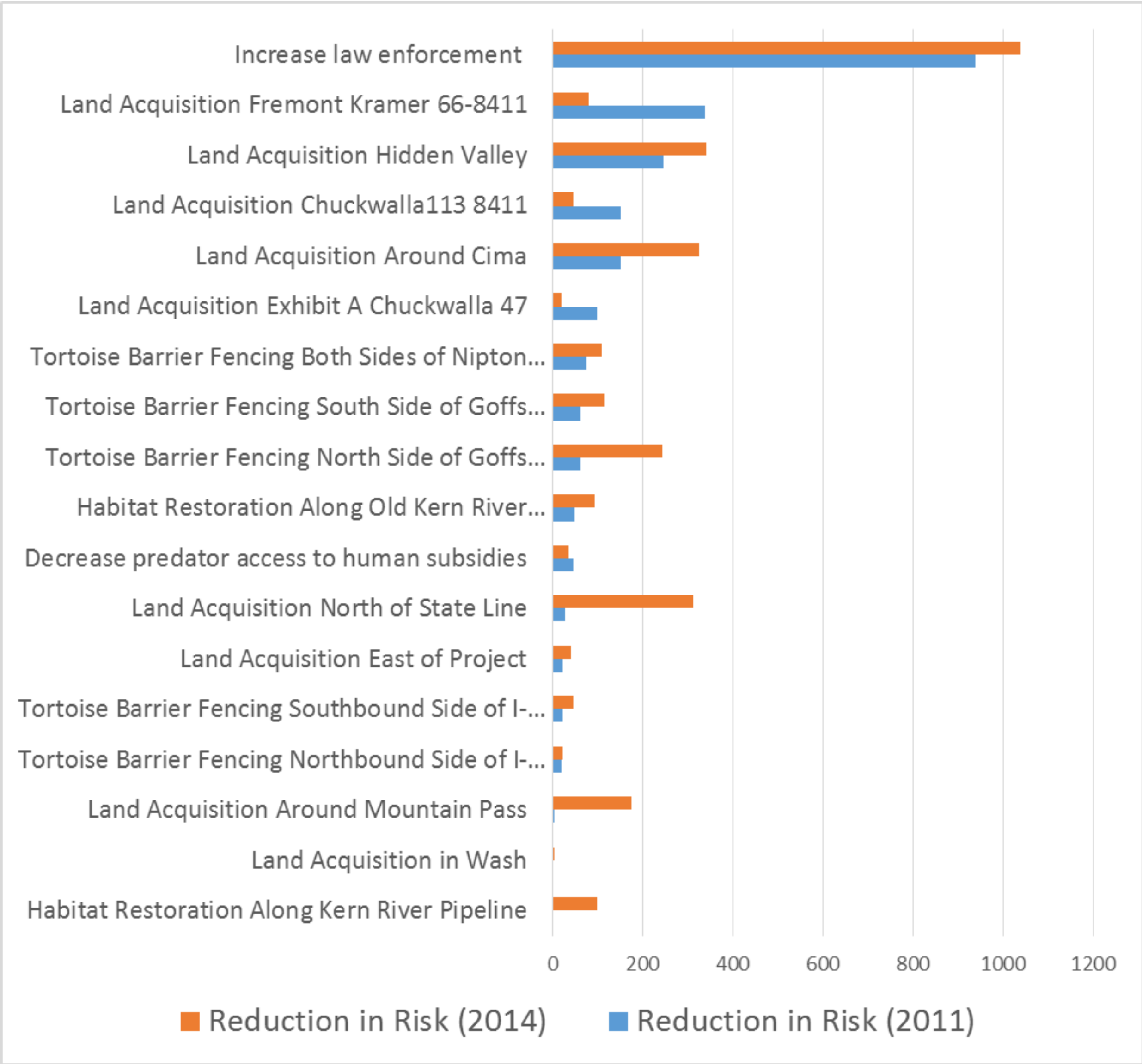
Table 14 and Figure 43 provide a comparative view of the estimated risk reduction resulting from the proposed ISEGS mitigation package, according to the 2011 and the 2014 SDSS system calculations. The project partners note that to allow direct comparison with 2011 estimates, the 2014 risk reduction values were multiplied by a factor of 10. This was because all threat layers in 2014 SDSS were normalized, so that the sum over the entire range equals 1,000,000. In the 2011 version of the system, the target normalization number 10,000,000 was used. The normalization target numbers were simply a convenience, so that system results are comparable when the scale factor of 10 is used.

Table 14: Risk Reduction Values for Recovery Actions in Proposed ISEGS Mitigation Package (2011 and 2014 System Calculations)

Management Actions	Reduction in Risk (2011)	Reduction in Risk (2014)
Decrease predator access to human subsidies	**46.11**	**36.88**
Raven Program at ISEGS	46.11	36.88
Increase law enforcement	**938.58**	**1039.29**
Law Enforcement	938.58	1039.29
Install and maintain tortoise barrier fencing	**274.11**	**537.01**
Both Sides of Nipton Road From I-15 to Nipton	74.49	110.15
North Side of Goffs Road From Goffs To Fenner	62.76	243.59
Northbound Side of I-15 from Yates Well To Nipton Road	20.42	21.95
South Side of Goffs Road From Goffs to Arrowhead Junction	62.76	115.84
Southbound Side of I-15 from Yates Well To Nipton Road	23.05	45.48
Land Acquisition	**1045.56**	**1346.59**
Chuckwalla113 8411	151.57	46.44
Exhibit A Chuckwalla 47	99.16	21.51
Fremont Kramer 66-8411	339.61	81.92
Hidden Valley	246.57	340.28
Land Acquisition Around Cima	151.32	324.22
Land Acquisition Around Mountain Pass	4.32	174.81
Land Acquisition East of Project	23.93	40.54
Land Acquisition in Wash	0.36	3.91
Land Acquisition North of State Line	28.72	312.97
Restore Habitat	**49.08**	**192.61**
Habitat Restoration Along Kern River Pipeline		99.03
Habitat Restoration Along Old Kern River Pipeline	49.08	93.58
Total Reduction in Risk	**2,353.44**	**3,152.38**

Source: Desert Tortoise SDSS

Figure 43: Graph of Risk Reduction From Specific Recovery Actions in Proposed ISEGS Mitigation Package (2011 and 2014 System Calculations)



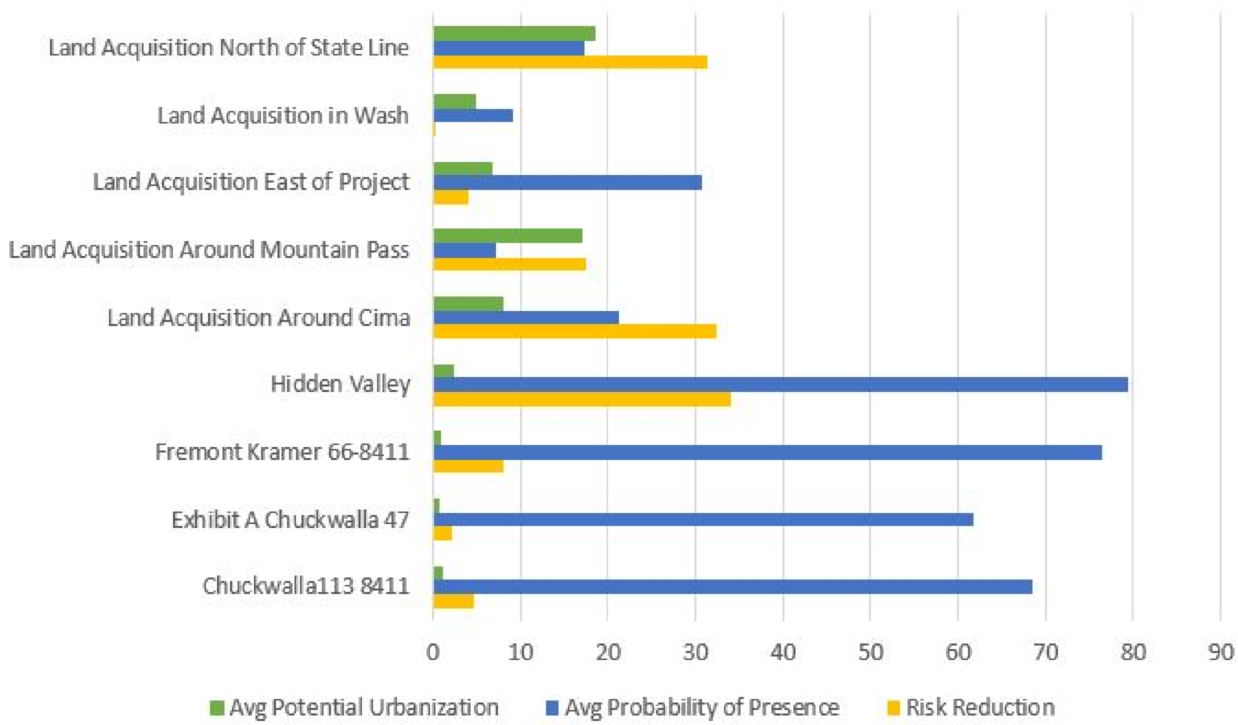
Graphical representation of reduction in risk to the tortoise population from specific recovery actions proposed for inclusion in the 2011 and 2014 calculations of the ISEGS mitigation package. The total estimated reduction in risk from these actions was 2,353 risk units (2011 SDSS) and 3,152 risk units (2014 SDSS).

Source: Desert Tortoise SDSS

Despite the various changes in the conceptual model and weights, and the relative contributions of the threat stress mechanisms on which the law enforcement management actions act, the reduction in risk was almost unchanged between 2011 and 2014. In addition, in both sets of calculations, the increase in law enforcement was the single most effective management action in the ISEGS proposed mitigation package. Despite the considerable changes to the effectiveness of individual land acquisition actions wrought by introducing the new Potential Urbanization model, for both runs the entire suite of proposed land acquisition actions were found to be cumulatively slightly more effective at decreasing risk to the tortoise as the single proposed management action of increasing law enforcement.

Based on the new potential urbanization model, the suite of proposed parcels for and acquisition reduced risk to the tortoise by 1,347 risk units in the 2014 system version, compared to the estimated reduction in risk of 1,045 risk units estimated in 2011. In the new model for land acquisition (See Chapter 2), the risk reduction estimated for a parcel being acquired now depends not only on the probability of presence where the parcel is located but also on the probability that that parcel might be developed in the future due to the threat of potential urbanization. For the proposed parcels in the ISEGS mitigation package, that potential is fairly low, varying from 18% to below 1% (Figure 44). Since in the 2011 calculations development was treated as 100% certain, this new model should greatly reduce the effectiveness of land acquisition actions. However this expected decrease from 2011 is offset in the 2014 model by the use of the total (direct and indirect) weight of the threat of urbanization to population change, compared to just the direct weight in 2011. Given that if land is acquired before it is developed, all downstream threats are prevented, using the total weight contribution is the appropriate choice.

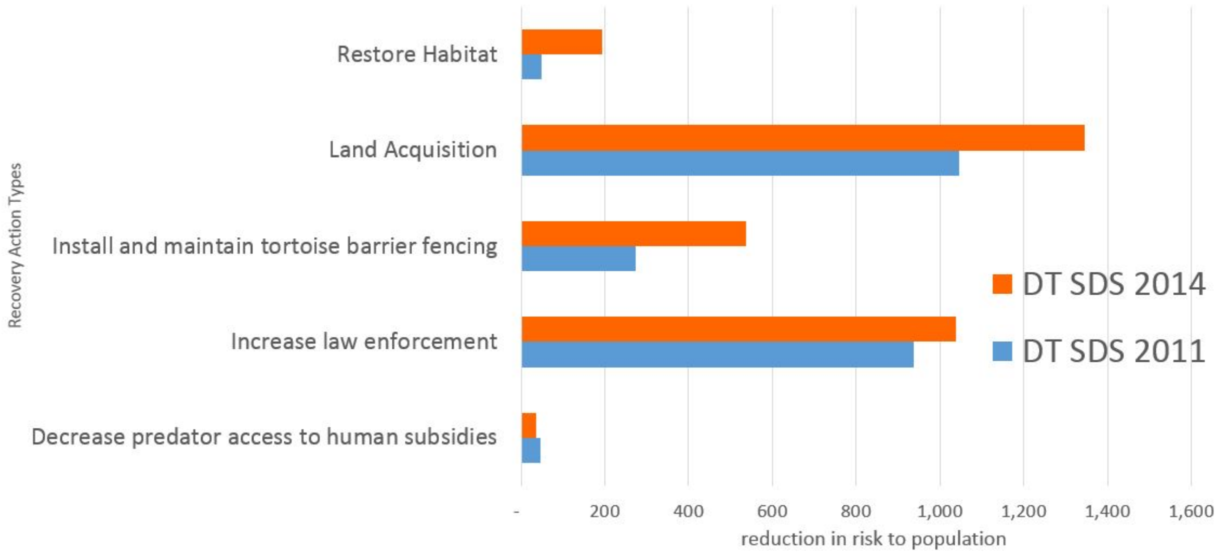
Figure 44: Reduction in Risk to Tortoise Population at ISEGS Through Land Acquisition (2014 System)



In the 2014 SDSS, reduction in risk through Land Acquisition is proportional to the product of Probability of Presence and Potential Urbanization. These two factors vary widely across the included land parcels.

Source: Desert Tortoise SDSS (2014 System version)

Figure 45: Comparative Reduction in Risk to Tortoise Population at ISEGS for Recovery Action Types (2011 and 2014 System Calculations)



Source: Desert Tortoise SDSS

As discussed earlier, the estimated effectiveness of increasing law enforcement was relatively unchanged between the 2011 and 2014 calculations, while the effectiveness of total land acquisition actions was somewhat higher in 2014 than in 2011 (Figure 45). The effectiveness of creating tortoise barrier fencing along highways rose by 96% in the 2014 calculation. This increase was a combination of a 10% increase in the contribution of threat-stress relationships to population change, more overlap of road effects due to increased decay distances in the spatial mapping of the effects of roads on tortoises, and more contributing traffic generators (e.g., landfills) in the 2014 threat layers.

4.3.5 Offset in Risk from ISEGS Project Impacts and Mitigation: 2011 and 2014

Combining impacts and mitigation provided a risk offset graph, comparing the increase in risk from project impacts, and the decrease in risk from proposed recovery actions. Figure 46 provides a comparative view of offset in risk calculated for ISEGS using the 2011 and 2014 SDSS.

Figure 46: Estimated Offset in Risk to Tortoise Population for ISEGS Project, Considering Impacts and Mitigation (2011 and 2014 System Calculations)

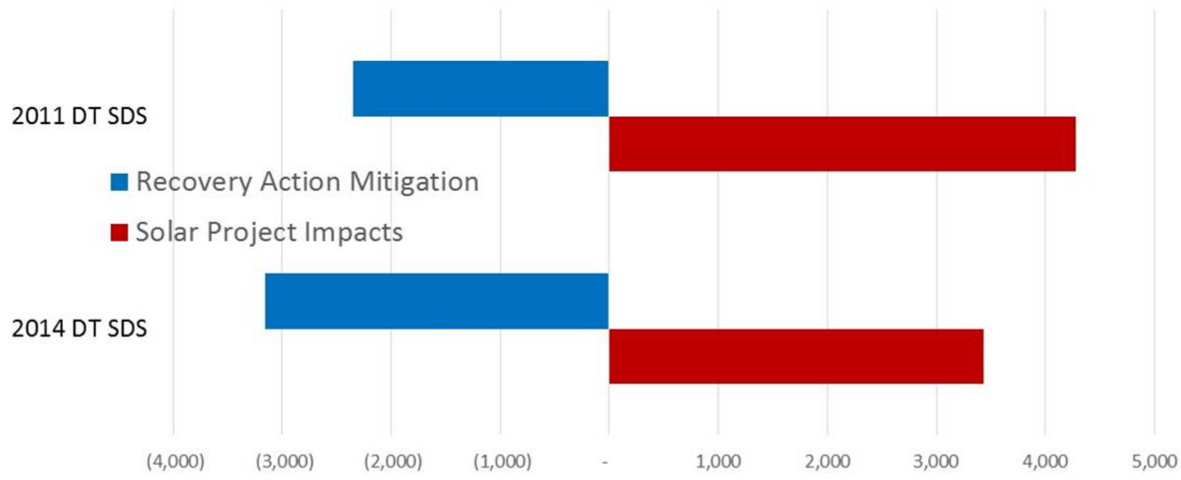


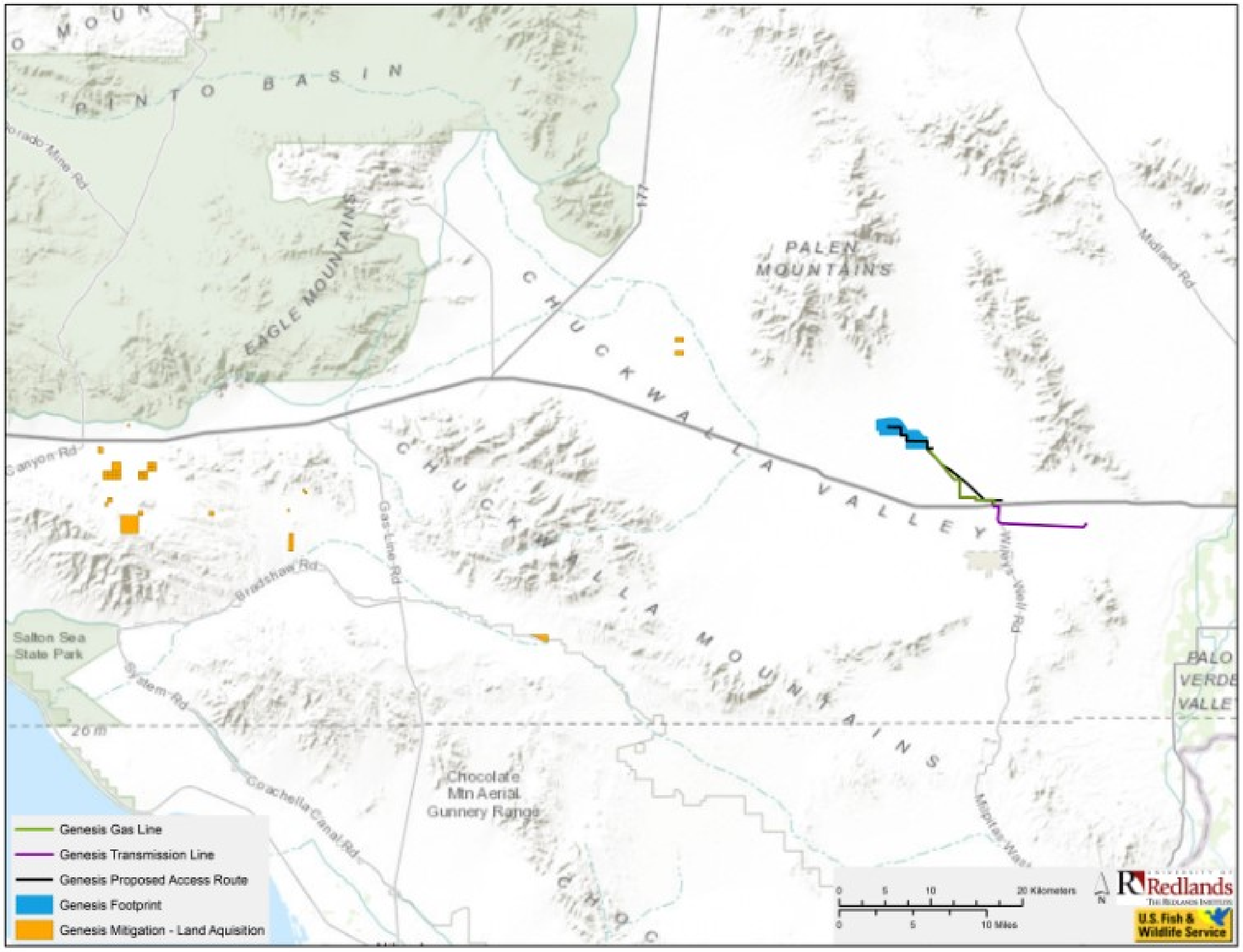
Chart shows change in risk from 2011 to 2014: increase in risk (red) due to ISEGS project related impacts, and decrease in risk (blue) due to proposed recovery actions in the ISEGS mitigation package.

Source: Desert Tortoise SDSS

4.4 Genesis Solar Energy Project Calculations (2014)

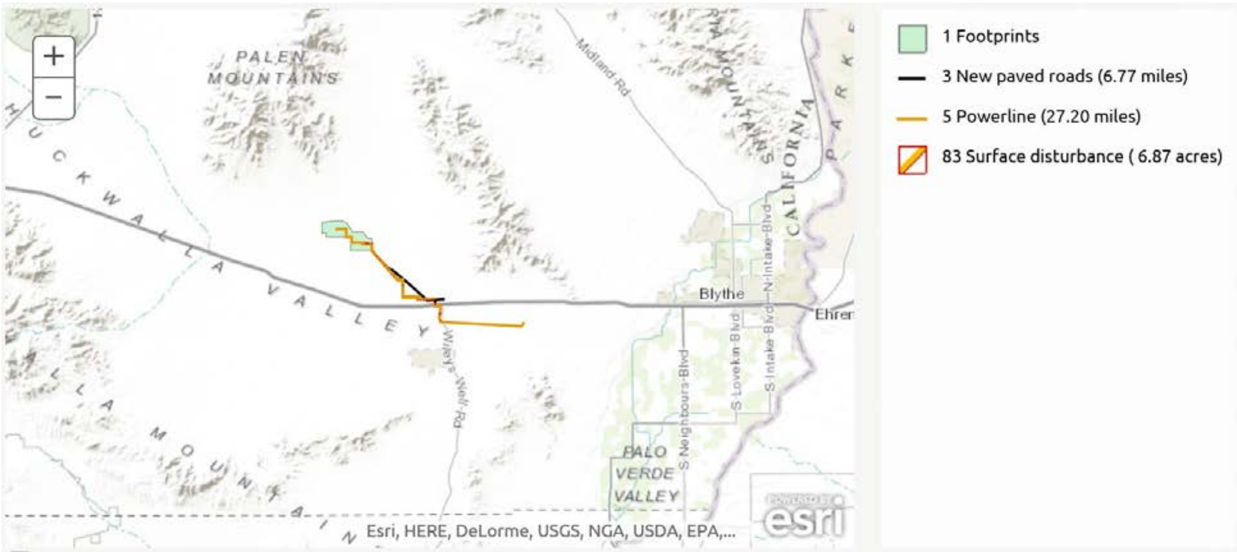
The Genesis Solar Energy Development Project is a concentrated solar power station built in two stages between 2013 and 2014 and located in the Colorado Desert on 1,920 acres (780 ha) of Bureau of Land Management land, in eastern Riverside County, California, about 25 miles (40 km) west of Blythe, in the Lower Colorado River Valley. This site was only tested with the 2014 version of the SDSS. The maps in Figures 47 and 48 show the proposed project area, including the project footprint and proposed accompanying mitigation package involving land acquisition.

Figure 47: Map of Genesis Solar Energy Project and Proposed Mitigating Land Acquisition



Source: Desert Tortoise SDSS

Figure 48: Map of Genesis Project Footprint Including Roads, Power Lines, and Surface Disturbance

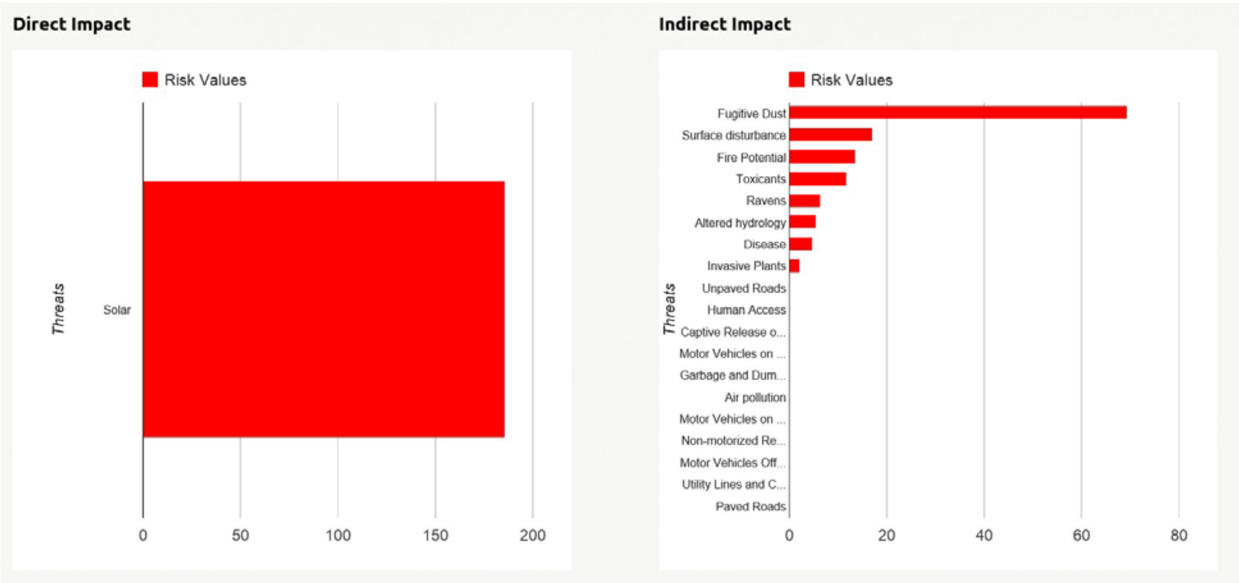


Source: Desert Tortoise SDSS

4.4.1 Genesis Solar Energy Project Impacts

The 2014 SDSS estimated an increase of 316 risk units, 185 (59%) as a direct result of placing the project and its supporting features on the landscape, and 131 (41%) due to indirect effects related to project elements such as new roads and power lines (Figure 49).

Figure 49: Estimated Increase in Risk to Tortoise Population From Genesis Project Direct and Indirect Impacts

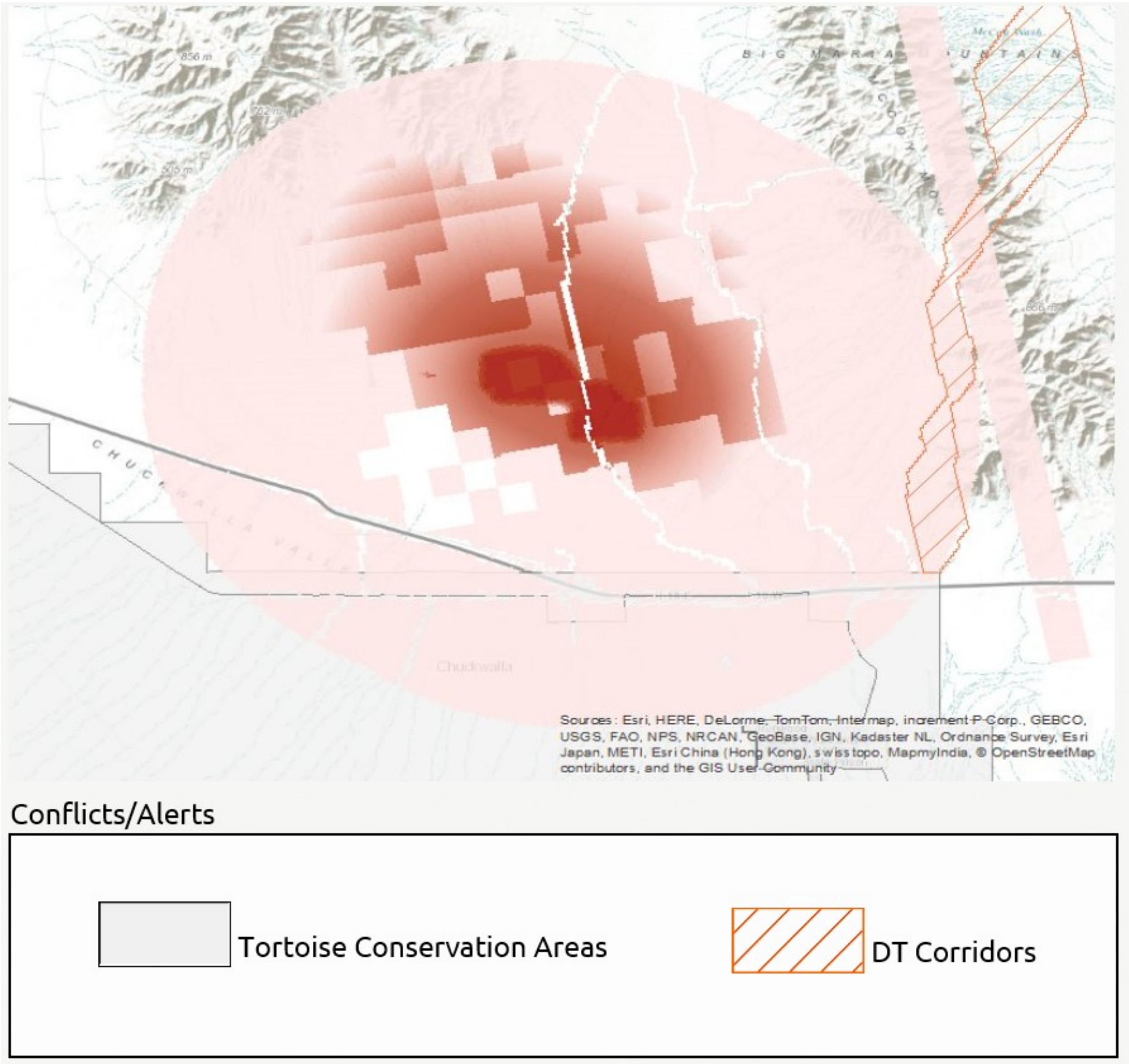


2014 system estimates of the direct impacts from the threat of solar energy development and impacts from the indirect threats that are increased by placing the Genesis project on the landscape. The horizontal scale represents risk units.

Source: Desert Tortoise SDSS

Figure 50 maps the change in overall risk across the landscape resulting from the Genesis project, as calculated by the 2014 SDSS version.

Figure 50: Spatial Distribution of Overall Risk to the Tortoise Population Resulting From Genesis Project



The higher the increase in risk, the deeper the hue of red.

Source: Desert Tortoise SDSS

4.4.2 Genesis Project Mitigation Calculations

The mitigation package associated with the Genesis solar energy development project, as provided to the project team by Wildlands, Inc. (2013, pers. comm.), included land acquisition and long-term management and maintenance in the form of a mitigation bank. To quantify the benefit to the tortoise, the team included not only the land acquisition itself, but also the management actions as proposed in the management plan for the mitigation bank. These management actions included signing and fencing, habitat restoration, garbage clean-up, fire management, and decreasing predator access to human subsidies. See Figure 4.13 above for the distribution of sites that were proposed for land acquisition and improvement for conservation purposes. Figure 51 shows the estimated reduction in risk to the tortoise population resulting from each of the proposed recovery actions in the Genesis mitigation package.

Figure 51: Reduction in Risk to Tortoise Population From Proposed Recovery Actions in the Genesis Mitigation Package

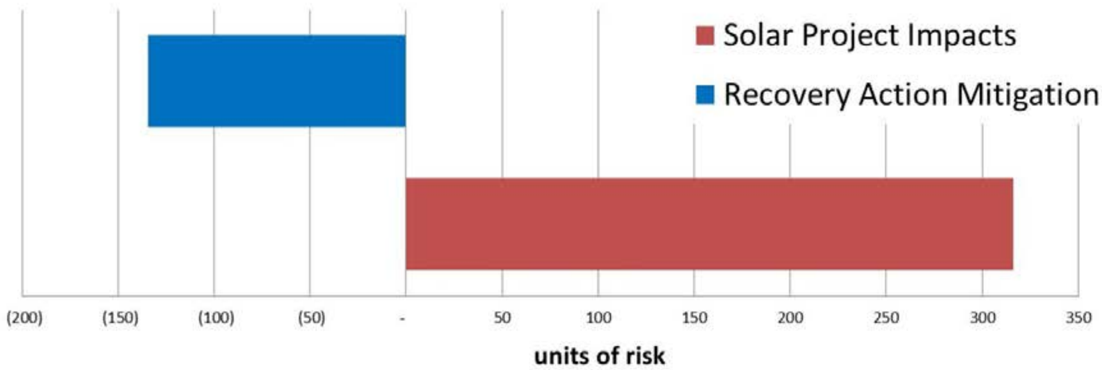
Estimated reduction in risk to the tortoise population, were management actions to be implemented as planned in the Genesis mitigation package (times 10 to match impact normalization).

Source: Desert Tortoise SDSS

4.4.3 Offset in Risk From Genesis Project Impacts and Mitigation (2014)

The risk offset graph below (Figure 52) compares the increase in risk from project impacts, and the decrease in risk from proposed recovery actions for the Genesis project.

Figure 52: Estimated Offset in Risk to Tortoise Population for Genesis Project, Considering Impacts and Mitigation



Estimated overall risk to the tortoise population, showing increase in risk due to Genesis project related impacts, and decrease in risk due to proposed recovery actions in the Genesis mitigation package.

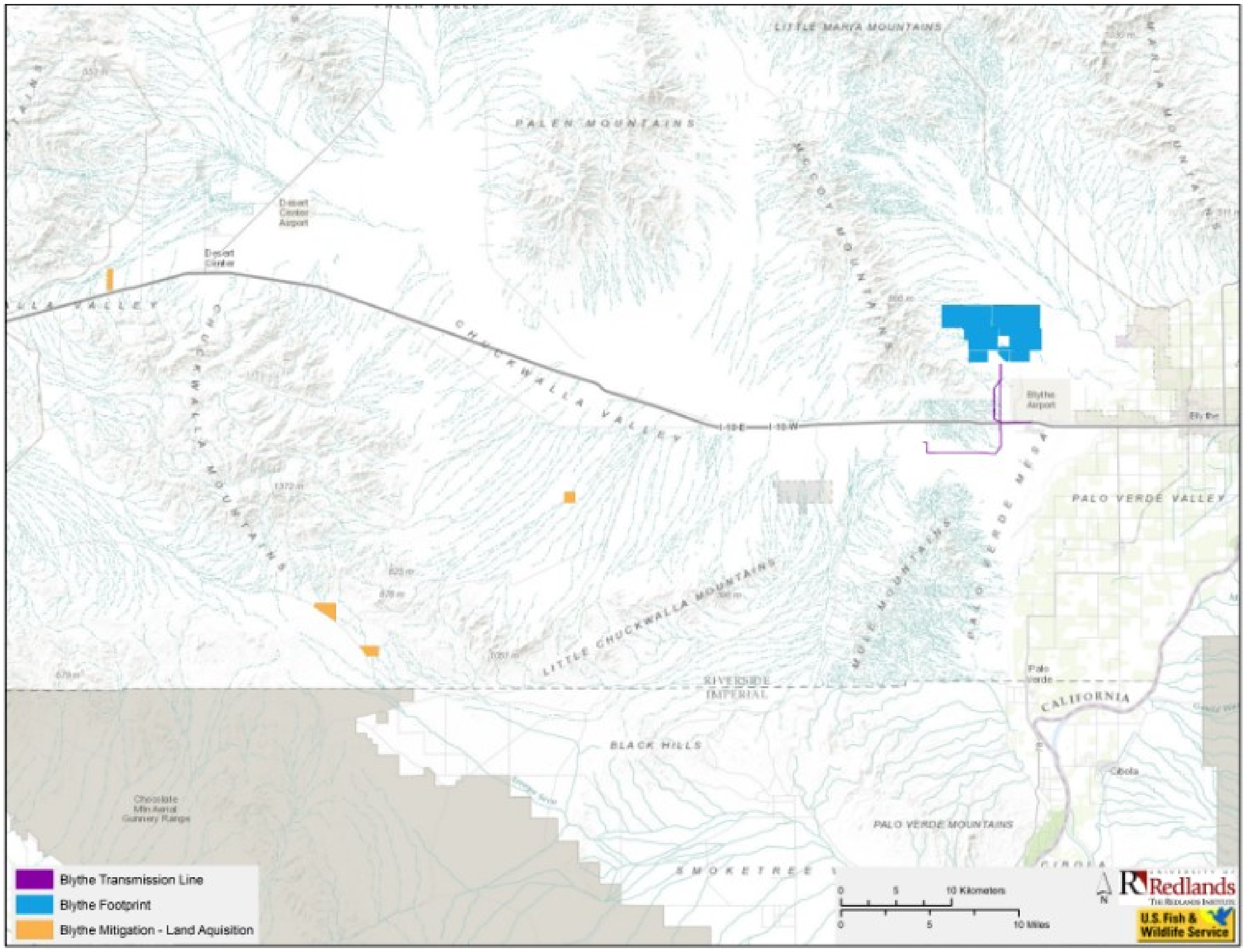
Source: Desert Tortoise SDSS

The area of proposed land acquisition actions in the mitigation package for the Genesis Solar Energy project is only 1.29 times that of the project footprint, whereas the ISEGS mitigation package was 1.79 times that of the solar plant. Without the large contribution of a management action such as law enforcement outside of the land acquisition parcels, the reduction in risk from proposed mitigation would be less than the increase in risk from developing the facility.

4.5 Blythe Solar Energy Project Impacts and Mitigation

The Blythe Solar Power Project is a proposed and approved power station in Riverside County, California. The footprints and information on the project used in test calculations were based on the 2012 proposed project (Figure 53). The project was originally approved for solar parabolic trough technology, but was later changed to photovoltaic. Construction under the new design began in 2015.

Figure 53: Map of Blythe Solar Energy Project and Proposed Mitigating Land Acquisition

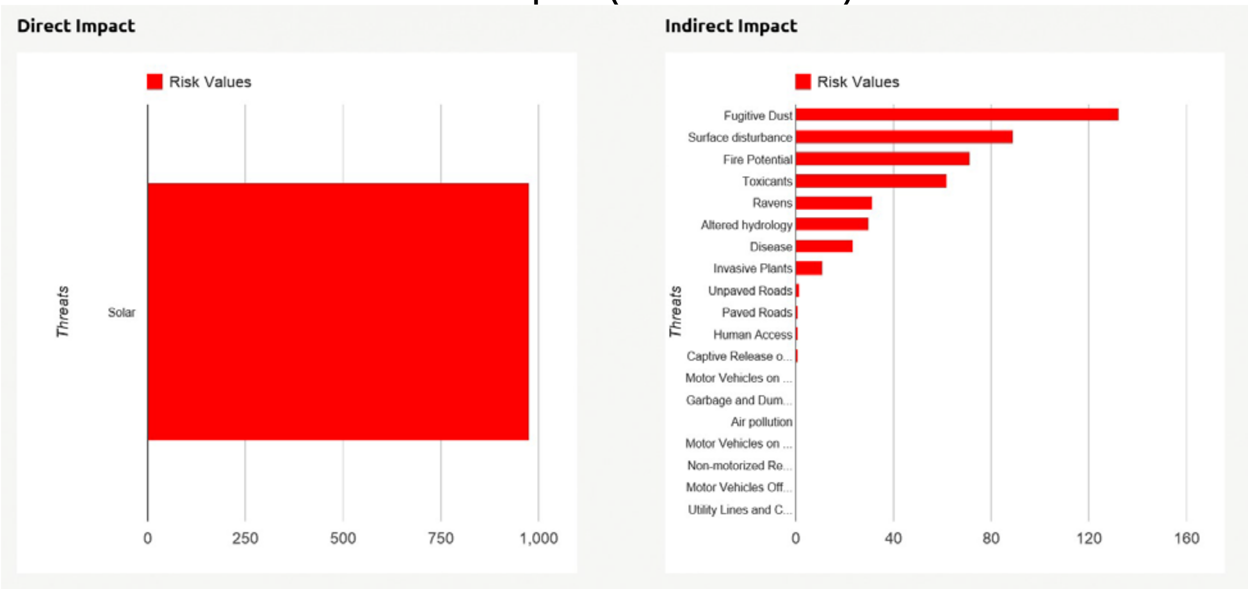


Source: Desert Tortoise SDSS

4.5.1 Blythe Solar Energy Project Impact Calculations

The SDSS estimated an increase of 1,431 risk units, 976 (68%) as a direct result of placing the Blythe project and its supporting features on the landscape, and 455 (32%) due to indirect effects (Figure 54).

Figure 54: Estimated Increase in Risk to Tortoise Population From Blythe Project Direct and Indirect Impacts (2014 Calculations)

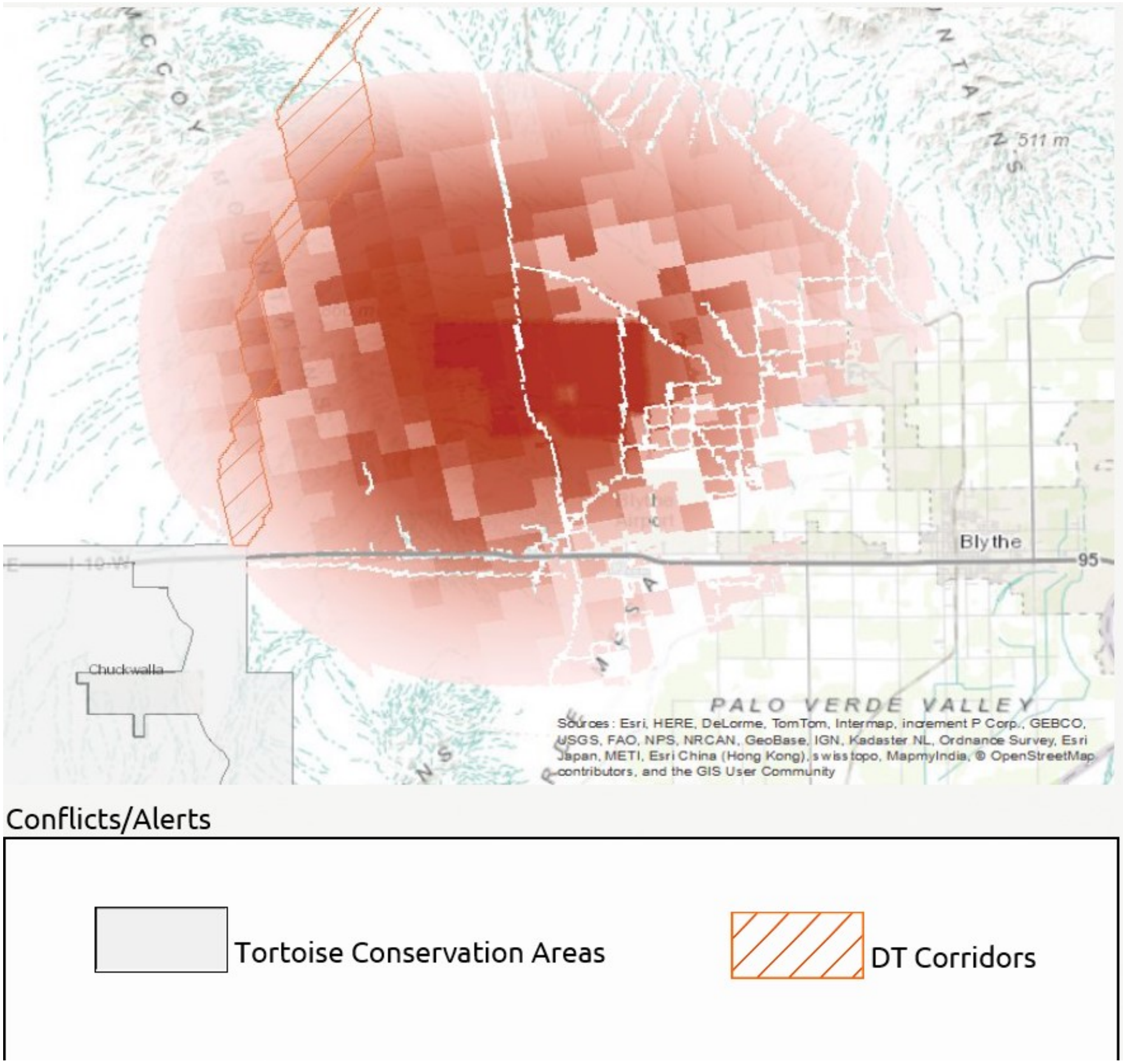


The horizontal scale represents risk units.

Source: Desert Tortoise SDSS

Figure 55 maps the change in overall risk across the landscape resulting from the Blythe project, as calculated by the 2014 SDSS version.

Figure 55: Spatial Distribution of Overall Risk to the Tortoise Population Resulting From Blythe Project



The higher the increase in risk, the deeper the hue of red.

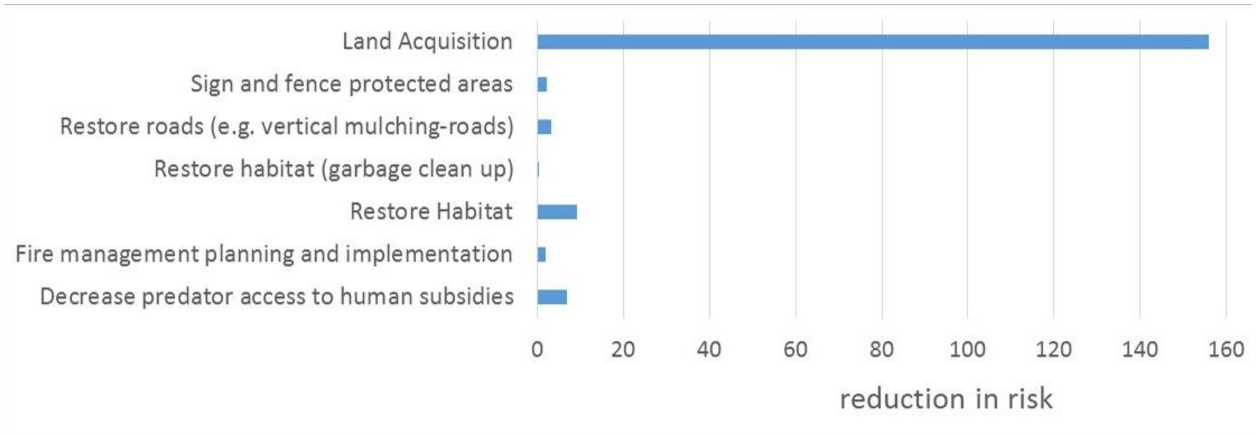
Source: Desert Tortoise SDSS

4.5.2 Blythe Project Mitigation Calculations

The proposed mitigation package associated with the 2012 Blythe solar energy development project included land acquisition and long-term management and maintenance in the form of a potential mitigation bank. As for Genesis, to quantify the benefit to the tortoise, the project team included both the land acquisition and the management actions as proposed in the management plan for the bank. These management actions included signing and fencing, habitat restoration, garbage clean-up, fire management, and decreasing predator access to human subsidies. See

Figure 53 above for the distribution of sites that were proposed for land acquisition and improvement for conservation purposes. Figure 56 shows the estimated reduction in risk to the tortoise population resulting from each of the proposed recovery actions in the Blythe mitigation package.

Figure 56: Reduction in Risk to Tortoise Population From Proposed Recovery Actions in the Blythe Mitigation Package



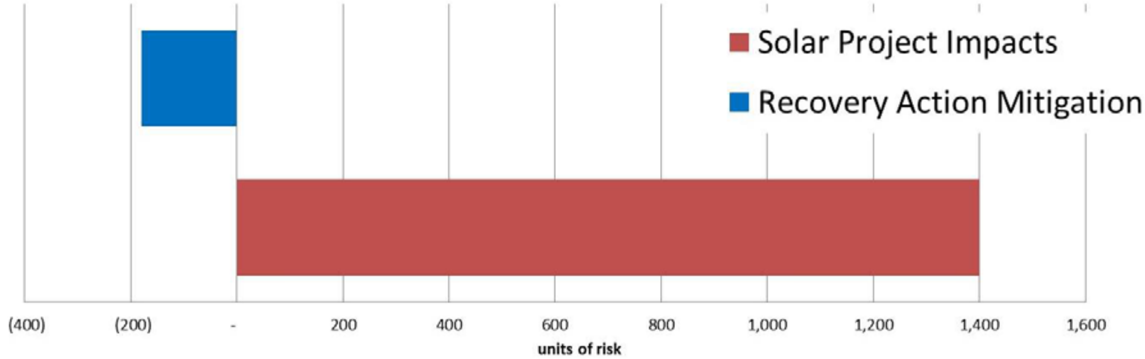
Estimated reduction in risk to the tortoise population, were management actions to be implemented as planned in the Blythe mitigation package (times 10 to match impact normalization).

Source: Desert Tortoise SDSS

4.5.3 Offset in Risk From Blythe Project Impacts and Mitigation

The risk offset graph below (Figure 57) compares the increase in risk from project impacts, and the decrease in risk from proposed recovery actions for the Blythe project

Figure 57: Estimated Offset in Risk to Tortoise Population for Blythe Project, Considering Impacts and Mitigation



Estimated overall risk to the tortoise population, showing increase in risk due to Blythe project related impacts, and decrease in risk due to proposed recovery actions in the Blythe mitigation package.

Source: Desert Tortoise SDSS

The area of proposed land acquisition, and associated management actions, 3.5 sq km, is only 14% of the area of the footprint of the Blythe solar plant itself (24.1 sq km). As such, the estimated reduction in risk of the mitigation is much smaller than the estimated increase due to implementing the proposed plant at the specified site.

4.6 Discussion of System Test Results for the Three Study Solar Energy Projects

The more significant differences in results for ISEGS from the 2011 and 2014 iterations of the Desert Tortoise SDSS were related to differences in the conceptual model, the new spatial processing of the land acquisition and the underlying data between these two system versions.

Across all three of the solar energy development projects, the ratio of direct to indirect impacts was remarkably consistent at roughly 60:40 despite different layout of the projects.

Only in the case of ISEGS did the risk reduction from the package of management actions come within the same order of magnitude as the estimated increase in risk from the proposed project. Given that building the project would immediately grade the site resulting in complete habitat loss, whereas many of the recovery actions will take time to have an effect, simple parity of mitigation and risk does not represent a neutral outcome for the tortoise. Note that the Desert Tortoise SDSS does not in its current version allow for any inherent difference in impacts between solar energy technology types beyond their footprint and ancillary infrastructure. That is, the impacts are considered the same whether the ground is covered with mirrors (heliostats) or photovoltaic panels, or whether the site is fully graded or if the vegetation is only mowed. The most salient characteristic is that they are surrounded by a tortoise fence that puts the site footprint beyond the population habitat. This modeling assumption can be revised if the science indicates it should be.

4.7 Sensitivity and Uncertainty Analysis for Proposed ISEGS Project

Another goal of this project was to improve the ability of the system to report on sensitivity analysis, and to generate error bars assigned to impact and mitigation calculations. Continuing work started under the previous project, the team investigated the sensitivity of model outputs (estimated change in risk to the tortoise population) to changes in model parameters, using the ISEGS project as a test case. The team planned to pursue two related investigations:

- Sensitivity of project results (outputs) to changes in model parameters, taken one at-a-time, and
- Analysis of uncertainty in the outputs, using Monte Carlo techniques with repeated model runs, based on concurrent random variations in those model parameters.

4.7.1 Variance in Risk Change Estimates

The Desert Tortoise SDSS is a complex computational system, whose outputs depend on both the input threat datasets and the many weights and parameters that describe the risk model. Different values for the inputs (i.e., weights and parameters, collectively, the system components) would likely result in different estimates of change in risk to the tortoise population. Although the system uses the best available data for weights and parameters, their quantitative values are not precisely known.

There are four primary sources for variance in the SDSS model: a) the weights for the links that make up the conceptual model (see Section 1.3.2); b) the parameters that control the spatial computation for each link; c) the input spatial threat layers; and d) the spatial probability of presence layer.

There are currently 450 weighted links in the conceptual model (see Table 15). The team examined variation in the changes in risk to population from both the impacts of the ISEGS project, and from the associated proposed mitigation package of recovery (management) actions.

Table 15 Summary of Weights in the 2014 SDSS Computational Model

Weight Type	Weight Type Abbreviation	Number
A Population Effect that contributes to Population Change	PE > PC	4
A Stress that contributes to a Population Effect	S > PE	44
A Threat that contributes to a Stress	T > S	101
A Recovery Action that suppresses a Threat to Stress mechanism	RA - (T > S)	152
A Threat that contributes to a Corollary Threat	T > T	149
	Total	**450**

Spatial modeling in the SDSS is performed at 100m x 100m resolution over the entire range, so that even with all the improvements in execution speed achieved in this project, full spatial recalculations of the system require minutes of CPU time. The sources of variation b), c) and d) above are all intrinsic to the spatial computation of the model. For practical purposes, the team segregated the resource-intensive computation of all the spatial tasks for the base calculation, which uses the input threat layers, the probability of presence layer and the T > T weights and spatial directives to generate the individual stress layers. Calculating the overall risk thereafter requires only the weighted sum, using the weights from the S > PE and PE to PC levels of the hierarchy. In spite of all the gains in computational speed reported in earlier sections of this Chapter and in Chapter 6, once it became apparent that the resource-intensive spatial calculations could only be improved so much without changing the entire architecture to employ parallel computing and knowing that tens of thousands of model runs would be required for the uncertainty calculations, the team concluded that only the variation due to the 450 weights could be included in this project.

4.7.2 Sensitivity of Results to One-at-a-Time (OAT) Changes in the Weights

In Section 4.3 of this chapter, the team calculated both (a) the *total increase in risk* to the tortoise population from implementation of the proposed ISEGS project and, (b) on the same scale, the *total expected reduction in risk* with implementation of the associated mitigation package (see

Figure 4.12). For this OAT analysis, the percent change in both of those totals is estimated when a weight's nominal value is increased by 10%. If a weight is already within 10% of its maximum scale value, the increase is from nominal value -10% to nominal value. Once the weight's value has been changed, that weight and its neighboring weights are renormalized to preserve the model requirement that they sum to 1.

The weights capturing the relative contribution of a threat to its corollary threats (T > T) are not included, as they are fixed in the initial spatial calculations. The mitigation package for the proposed ISEGS project contained only 5 management (recovery) action types (see Table 14). The effectiveness weights of the other 20 recovery action types on the threat to stress mechanisms they suppress have no effect on the risk totals, and they too were excluded. Similarly, threat to stress mechanisms not affected by the five recovery action types included in the mitigation package would also have no effect and were excluded.

Table 16: Number and Effect of Largest Changes of Weights (for Both Impact and Mitigation Totals) Examined in OAT Analysis

Weight Type	No Change	<=1%	1-2%	>= 2%	Totals by Type
PE > PC	0	2	1	1	4
S > PE	11	19	3	11	44
T > S	33	35	23	5	96
RA - (T,S)	40	14	1	2	57
Totals by Type	**84**	**70**	**28**	**19**	**201**

In all, the ISEGS calculation was rerun for 201 individual weights, and the % change in risk increase from total impacts and risk decrease from total mitigation was recorded. As can be seen from Table 16, 47 (28 + 19) of the weights would change one or both of the totals by at least 1%, confirming how sensitive the SDSS outputs are, at least in the specific case of the proposed 2011 ISEGS project, to those weights. Indeed 19 (9% of the 201 weights) change at least one of the totals (impact or mitigation) by 2% or more.

The changes wrought by varying the nominal weights values of those 19 by 10% are shown in Figure 58. That the total mitigation output is most sensitive to the contribution weight of Urbanization to Habitat Loss (T > S) is no surprise. The nine proposed land acquisition actions provide 43% of the total risk reduction from mitigation, and their value is linearly dependent on that weight.

Figure 58: Sensitivity of Total Changes in Risk From the Proposed ISEGS Project and its Mitigation Package

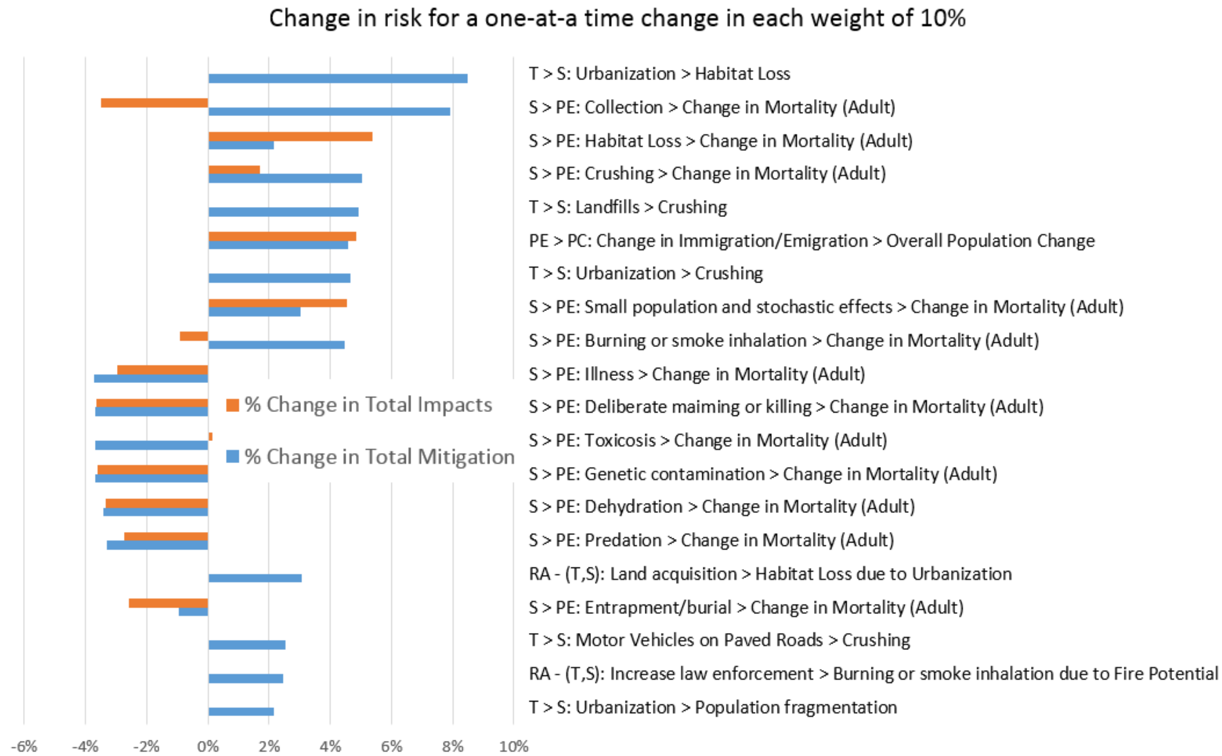


Figure shows responses to a 10% change in each weight taken one-at-a-time. Only those weights that produced at least a 2% change in risk in either the total impacts or total mitigation are shown. Bars on the right hand side indicate that total impacts (orange) or total mitigation (blue) increased as the particular weight was increased.

What may be more surprising is that the contribution of Immigration/Emigration to overall population change is the only top level (PE > PC) weight to appear in the graph. This supports what the authors observed in their aspatial OAT analysis of the conceptual model (Darst et al 2013). Basically the same stresses contribute to both Adult and Juvenile mortality, so dropping a weight contributing to one is somewhat compensated by its contribution to the other. In the spatial calculations for this project, if a stress is present in an area, it again contributes to both mortality population effects, so the compensation continues.

Two general patterns exhibited in the graph are of note. Firstly, since the amount of risk suppressed by a recovery action is proportional to the product of that recovery action times the risk associated with the threat-stress mechanisms it suppresses: if a weight increases the *amount of risk contributed* by that threat-stress mechanism, it also increases the *amount of risk suppressed* by that recovery action. For most of the 19 weights to which the totals are most sensitive, Figure 4.24 shows that total impacts and total mitigation changes are in lock step. Only for a few weights such as S > PE: Collection > Change in Mortality (Adult) does an increase in a weight lead to an *increase* in total mitigation, but a *decrease* in total impacts. This usually occurs when the link the weight quantifies is directly in the path of multiple threat-stress mechanisms the recovery action suppresses, but is a weight whose increase reduces (because of normalization) other weights that heavily support the impacts calculation.

Secondly, the graph suggests that changes in the values of threat to stress weights only contribute to changes in total mitigation. This is an artifact of the current data export from the SDSS, which does not support recalculation of impacts using the threat to stress weights. This will somewhat under-represent the variance in total impacts in the next section, but can be fixed in the future.

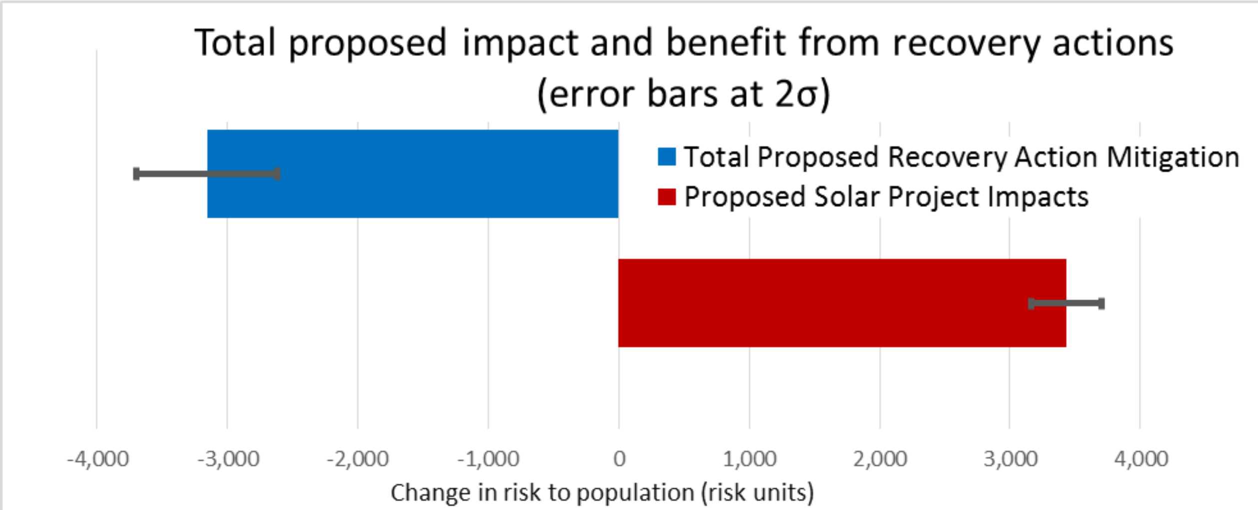
4.7.3 Uncertainty in the SDSS Outputs for the Proposed 2011 ISEGS Project

Uncertainty analysis focuses on quantifying the uncertainty in the outcomes, represented as error bars on the outcome values, based on variation in the inputs. The team again restricted themselves to variation in the 201 weights that could affect the outcomes of the calculations for the proposed 2011 ISEGS project.

The recorded variance in the expert surveys used to elicit the T >S, S> PE weights and the approach used to derive the PE > PC weights from the Doak et al. (1994) paper suggested that a normal distribution with a standard deviation of 25% was a reasonable probabilistic model for the variance inherent in those weights (Darst et al 2013). Independently, taking the elicited best/worst estimates for the effectiveness weights for those recovery actions used in the proposed mitigation package for ISEGS, a normal distribution with standard deviation of around 25% also is appropriate for those weights.

For this project, the team modified and improved the SDSS Spatial Sensitivity Analysis (SSA) tool to use (a) Monte Carlo techniques to generate weights values for each simulation run, according to the variance distributions above; (b) the new approach to calculating risk reduction from Land Acquisition management actions (see Section 2.1); and (c) new data outputs from the spatial portion of the SDSS model. With the remaining 201 weights as free parameters subject to uncertainty in their values in the computational model, the team expected that around 10,000 model runs would be required before statistical variables (such as standard deviation) of the distribution of output values for total impacts and total mitigation for all runs stabilized. Experiments of up to 400,000 model runs were implemented and the team observed that stability was well established by 40,000 simulations, so that number was used for the subsequent uncertainty analysis.

Figure 59: Lower Estimates of Uncertainty in Total Impacts and Mitigation for Proposed 2011 ISEGS Project



Shows the uncertainty in the estimates of risk increase from all impacts, and in the reduction in risk from all proposed management actions, based only on variance of all higher level contribution and recovery action effective weights.

In Figure 59, the error bars represent 2-sigma above and below the estimated nominal values (output from the SDSS with no variance; see Figure 46). For the set of weights whose variance was included in the simulations, the standard deviation for total impacts for the proposed 2011 ISEGS design is estimated as 272 risk units, associated with the nominal value of 3,434 risk units. The estimated standard deviation for the total reduction in risk due to the proposed mitigation package is 540, associated with the nominal value of 3,159 risk units.

The uncertainty in total mitigation values is much greater than that for the impacts, which is to be expected given that the impacts on population recovery are immediate, while the mitigating effect of some recovery actions may only be fully realized decades later (e.g., future threats averted through land acquisition). This is reflected in the high uncertainty assigned to their weights, even though the actions themselves and their effects may be well known. For instance, tortoise fencing by the sides of roads can be very effective; however the fences will have to survive intact for years before their effect may be seen in the population.

With the same limitations and assumptions, in the future the Desert Tortoise SDSS SSA could calculate the likelihood that total mitigation would be larger than total impacts (by calculating the variance in the difference over the simulation runs). Should regulators decide to adopt a specific mitigation to impacts risk reduction ratio (e.g., 3:1 for a proposed project), it would then make sense to use the SSA to calculate the likelihood that the minimum ratio would be met for that project.

4.7.4 Sensitivity and Uncertainty Analysis Summary

The SDSS OAT tool reveals those weights to whose variance the SDSS system is most sensitive. Figure 57 provides a guide for desert tortoise scientists as to which contribution or effectiveness links are most critically in need of improved quantification.

The SDSS SSA can generate uncertainty estimates simultaneously for both the increase in risk due to impacts and decrease in risk due to mitigation for a proposed project. Standard deviations were estimated based on Monte Carlo simulations on 40,000 runs. However, in the face of computational challenges to run 40,000 simulations for full spatial recalculations, the team only allowed for variance in a large subset of possible sources of input uncertainty. Based on the correlated (lock step) responses of the outputs to increases in weights in the OAT analysis, and the team's experience with other aspatial uncertainty analysis, including the missing variance of the weights at the lower levels of the model (T > T) would not add much additional uncertainty in the outputs.

However, the team does believe that modeling spatial variance in the input threat layers and the probability of presence layer may add significant variance. By necessity, most of the impacts and recovery actions take place on different areas of the landscape. The spatial layers may exhibit different amounts of uncertainty in those differing area, and that varying uncertainty propagated through the SDSS may well generate more uncertainty in mitigation outputs than in more localized impacts estimates.

The cost of full spatial calculations could be managed by creating 1000s of variations of the spatial threat to stress mechanism layers ahead of the full Monte Carlo runs. In a full run, the higher level weights could be sampled as above, and then combined with pre-sampled threat-to-stress mechanism spatial layers, providing suitable sampling algorithms are developed. This approach would provide a full accounting of output uncertainties based on all input uncertainties for the SDSS. Until then, Figure 59 represents a lower estimate of the uncertainties in the outputs of the Desert Tortoise SDSS system.

CHAPTER 5: Exploring Hypotheses About Adult Tortoise Density

5.1 New Abundance Data for Desert Tortoise Population

Models in the Desert Tortoise SDSS aggregate spatial information about threats in desert tortoise habitat to generate predictions about the relative contributions of these threats to the risk to the tortoise population (Murphy et al. 2013). The system also incorporates information about probability of presence of tortoises to calibrate this risk to the population. Until recently, the lack of range-wide population density estimates and their trends over time, has prevented development of the system to directly predict population change.

During this project, a data set estimating large-scale tortoise density trends became available (Allison and McLuckie, in prep.). The newly analyzed trends of adult tortoise density are from 2004 to 2012 and cover 17 designated Tortoise Conservation Areas (TCAs; Table 2; Allison and McLuckie in prep.). From Allison and McLuckie's abstract:

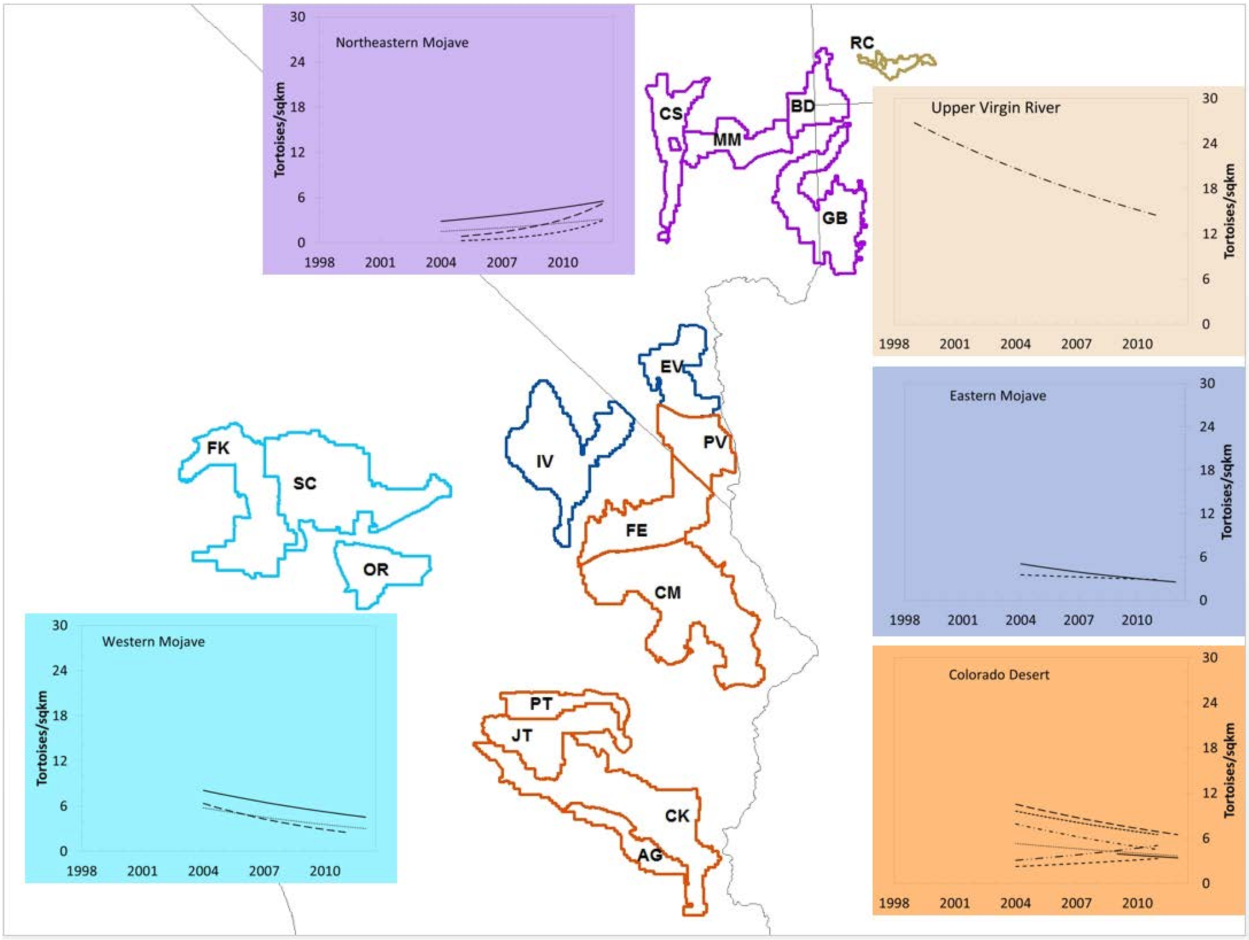
> "Mojave desert tortoises (*Gopherus agassizii*) are distributed widely and at low densities, so description of species-level status and trends has required a survey method that is statistically robust and can be applied on a large scale. …. Distance sampling from line transects has been used in Utah since 1999 and range-wide since 2004 to estimate density of Mojave desert tortoises in tortoise conservation areas (TCAs) where land management does not conflict with recovery objectives for this listed species. We used these estimates to compare a set of models to describe patterns in density based on linear and quadratic response over time, spatial variation between TCAs and recovery units, and proportion of survey teams with previous experience. The best model describing range-wide patterns in $\log_e$-transformed adult tortoise densities reflected linear proportional trends in density that differed by TCA in magnitude and/or direction."

These trends, and the underlying annual density estimates, provided an opportunity for the project team to evaluate different hypotheses about the variability in density estimates, and investigate whether SDSS outputs show consistency with observed abundance trends.

5.2 Approach

The Desert Tortoise SDSS aggregates information about threats to tortoises, converting these into levels of stresses, which in turn contribute to particular population effects (births, deaths, migration) to create an aggregate risk to local populations. These are *relative* risks, indicating the predicted *proportional change* in local tortoise populations, because there are few data available to quantify the *absolute* effects of different threats on tortoise populations (Boarman 2002; Boarman and Kristan 2006; USFWS 2011; Averill-Murray et al. 2012). The recently reported changes in density (Figure 60) suggested exponential growth/decay over the years, which is also a measure of proportional rather than absolute change in density.

Figure 60: Changes in Observed Densities for Tortoise Conservation Areas



Change in observed densities for the 17 TCAs, grouped by recovery units: Northeastern Mojave (purple, upper left); Upper Virgin River (pink, upper right); Eastern Mojave (blue, middle right); Colorado Desert (orange, lower right); and Western Mojave (aqua, lower left). The period of observation varies somewhat by TCA. The trend for each TCA is represented by a curve. Observed rates of change all indicated decreasing abundance, with the exception of all four TCAs in the Northeastern Mojave Recovery Unit and two TCAs in the Colorado Desert Recovery Unit.

Source: From presentation to Desert Tortoise SAC, based on Allison and McLuckie (in prep.)

In its first investigation, the project team therefore modeled these estimates of proportional change in density using measures relative to proportional risk. Each of these models was also corrected based on probability of tortoise presence, in case the threats that act in favorable habitat have different impacts in poor habitat where there are fewer tortoises. Because the population effects (PE) in the SDSS include adult survivorship, the project team also tested various combinations of PE in predictions of adult tortoise density patterns. The team tested linear combinations of the components of the system as different models explaining the 9-year proportional trends in density of adult tortoises (larger than 180 mm midline carapace length). Models that included only habitat potential, the system's own altered habitat potential (AHP), historical precipitation, and even the observed density itself were all null models, testing whether threat components of the Desert Tortoise SDSS are needed to explain observed trends (rates of change) in desert tortoises.

Success of the Desert Tortoise SDSS models to predict ongoing population trends, through this first investigation, would indicate completeness of the factors incorporated and correctness of the estimated model linkages. Failure of the SDSS models to predict current population trends might arise if the models are incomplete or incorrectly specified, or due to many other factors including quality of modelled information, identifying spatial scale at which the threats might act, and quality of the population trend estimates.

The project team also pursued two additional investigations with these abundance data. In a second investigation, the project team compared the same group of models to see which variables were most useful for predicting the observed density in each TCA. The observed density used was the average of current density over the last three years of available data for that TCA. Use of current density as the response variable tested the general hypothesis that given the large increase in threats in recent years, the current threats represented by threat layers in the system essentially represent cumulative threats; in other words, the level of risk posed by current threats swamps the cumulative risk posed by older threats on the landscape. Under this assumption, the observed tortoise densities would be the most accurate reflection of their population impacts.

Thirdly, the project partners investigated whether the positive trends in all four TCAs in the Northeastern Mojave are predicted by historical recovery actions in the TCAs. This might suggest that recovery actions previously taken to manage tortoises in these TCAs were at least partially successful in mitigating the risk to the population.

5.3 Methods

5.3.1 First Investigation: Exploring Hypotheses About the Causes in Variability in Tortoise Trends Across TCAs

The project partners created a series of explanatory models in Excel that are linear combinations of weighted aggregated threat outputs of the Desert Tortoise SDSS, with or without multiplication by the probability of presence layer. These predictive models were selected based on the risk to population (M1 and M2 in Table 17) and population effects (PE) levels of the SDSS conceptual model (M10 through M103 in Table 17). The project team considered one explanatory model (M1) based on the overall estimate of risk to the population. The M1 explanatory model risk is the product of the (weighted) aggregate threat estimate in the system, calibrated by multiplying it by the probability of presence (POP). Also included was an explanatory model (M2) representing just the aggregate threat estimate.

The project partners chose to look at combinations of the PE outputs because of uncertainty in the weights assigned to them in the conceptual model that represent their contributions to overall population change. The partners did not explore all possible combinations of individual population effects, but were guided by parameter estimates from the full models of additive PE effects (M10, M11). Instead of pursuing an exhaustive combinatorial analysis of PE variables, with or without POP, the project partners pursued the combinations that seemed most likely to explain the observed trends. This was in keeping with the intuitive information-theoretic approach taken in this investigation, as described later in this chapter, using the second-order Akaike Information Criterion (AICc; Burnham and Alexander 2002).

Table 17: Explanatory Models Based on Population Effects (PE) and Probability of Presence (POP) Selected Directly From the Desert Tortoise SDSS

Model ID	Model Description
M1	Risk to Tortoise (equals Aggregate Threat to Tortoise X POP)
M2	Aggregate Threat to Tortoise
M10	(Sum of all 4 Population Effects) X POP
M11	(Sum of all 4 Population Effects) w/o POP
M103a	Sum 3 PEs (Adult Mortality, I/E, Reproduction) X POP
M102ar	Sum 2PEs (Adult Mortality, Reproduction) X POP
M102aie	Sum 2PEs (Adult Mortality, I/E) X POP
M100	1 PE (Adult Mortality) X POP
M101	1 PE (Reproduction) X POP
M102	1 PE (Juvenile Mortality) X POP
M103	1 PE (Change in IE) X POP

Source: Desert Tortoise SDSS

5.3.2 Second Investigation: Exploring Relationships With Single Associated Data Sets Outside the SDSS

The project team also investigated a separate set of explanatory models based on single associated data sets (Table 18) outside of the SDSS (M3-M7) such as mean precipitation in the Fall and Winter months over the last 20 years; historical fire; a human access layer (Theobald, 2008); the team's altered habitat potential layer (AHP; see Chapter 3); and the original 2009 USGS Habitat Potential layer. This approach was intended to explore whether the observed densities and trends could be explained by a relatively simple variable, such as precipitation or habitat potential.

Table 18: Explanatory Models Based on Individual Associated Data Sets Outside the SDSS

Model ID	Model Description
M3_PPT	Mean Oct-Mar 2004-2012 Precipitation (PRISM)
M4_HisFire	Mean Historical Fire attenuated by time over 100 years
M5_HumAccess	Human Access (Theobald 2008)
M6_BaseAHP	Current Altered Habitat Potential
M7_HabPot	Nussear et al. (2009) Habitat Potential
M8_3YrDensity	Average Density most recent 3 Years

Source: Desert Tortoise SDSS

All analyses were conducted at the spatial scale of TCAs used by Allison and McLuckie (in prep.) and the 17 TCAs were the sample size for all analyses.

The project partners used the average value of a given variable over each of the 17 TCAs, and used linear regression and information-theoretic criteria (second-order Akaike Information Criterion; AIC_c) to rank models based on their fit to 1) slope of the logarithm (ln) of observed densities; and 2) most recent average 3-year density.

To remove the influence of the widely varying size of the TCAs, the values of variables were then calculated as their average current value over the 17 TCAs. The team calculated the power of each explanatory model to predict the slope of the natural log of densities (Table 19, Figure 61). This slope is roughly equal to the annual proportional change in density.

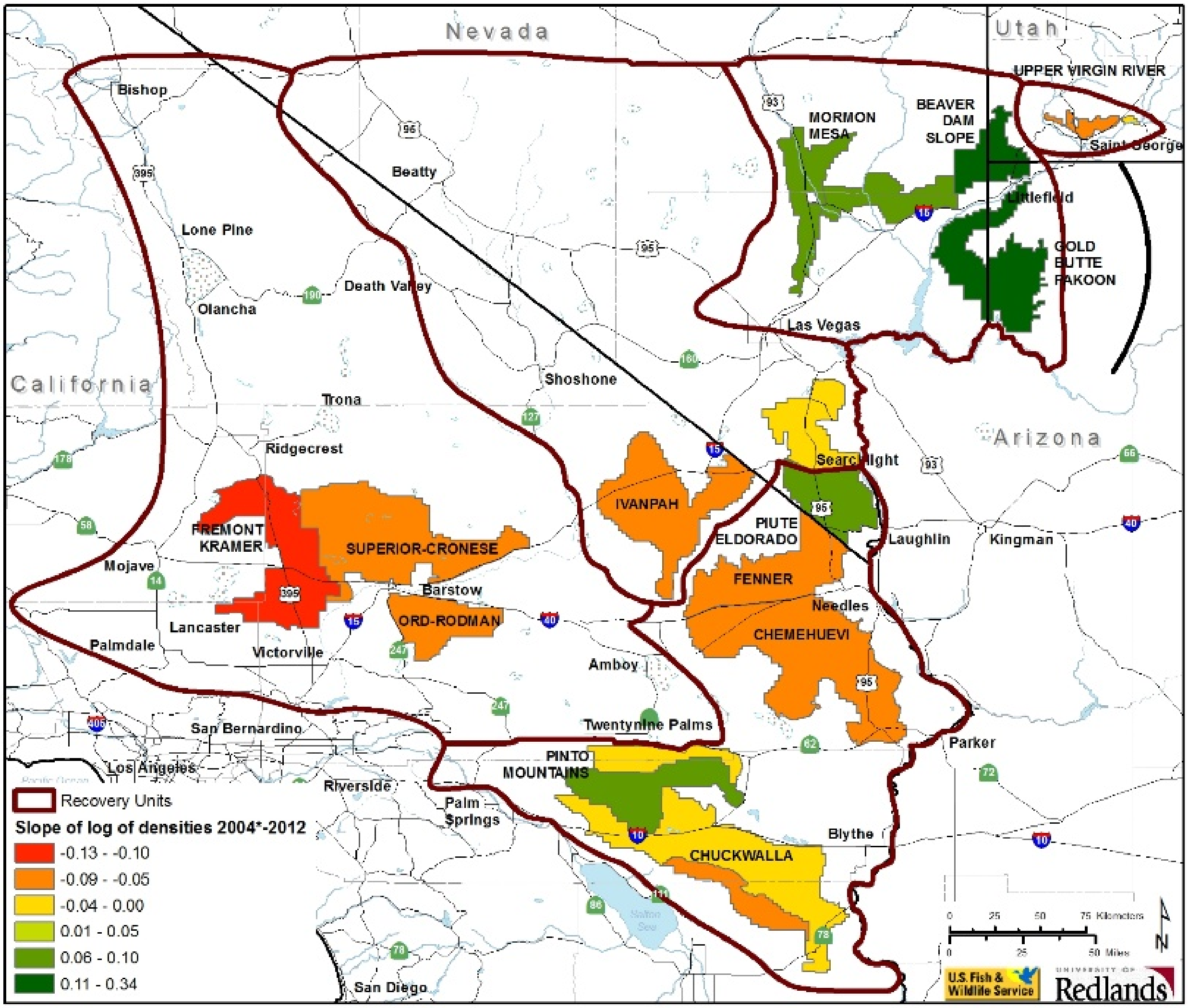
Table 19: Slope (Per Year) of the Log (ln) of Density Estimates (2004-2012) Within Each TCA

Recovery Unit	Tortoise Conservation Area	Slope of ln(Density)
Colorado Desert	Chocolate Mountain Aerial Gunnery Range (AG)	-0.061
Northeastern Mojave	Beaver Dam Slope (BD)	0.261
Colorado Desert	Chuckwalla (CK)	-0.046
Colorado Desert	Chemehuevi (CM)	-0.080
Northeastern Mojave	Coyote Springs Valley (CS)	0.092
Eastern Mojave	Eldorado Valley (EV)	-0.029
Colorado Desert	Fenner (FE)	-0.056
Western Mojave	Fremont-Kramer (FK)	-0.132
Northeastern Mojave	Gold Butte-Pakoon (GB)	0.343
Eastern Mojave	Ivanpah (IV)	-0.086
Colorado Desert	Joshua Tree (JT)	0.055
Northeastern Mojave	Mormon Mesa (MM)	0.083
Western Mojave	Ord-Rodman (OR)	-0.072
Colorado Desert	Pinto Mountains (PT)	-0.048
Colorado Desert	Piute Valley (PV)	0.071
Upper Virgin River	Red Cliffs Desert Reserve (RC)	-0.051
Western Mojave	Superior-Cronese (SC)	-0.081

Source: Table 4 from Allison and McLuckie (in prep.)

As can be seen from the above table, 6 of the 17 TCAs show increasing population trends. Five of these TCAs are in the eastern half of the desert tortoise range, and 4 are the TCAs that comprise the Northeastern Mojave Recovery Unit (Figure 61).

Figure 61: Map Showing Slope of the Log (ln) of Density Estimates (2004-2012) for TCAs

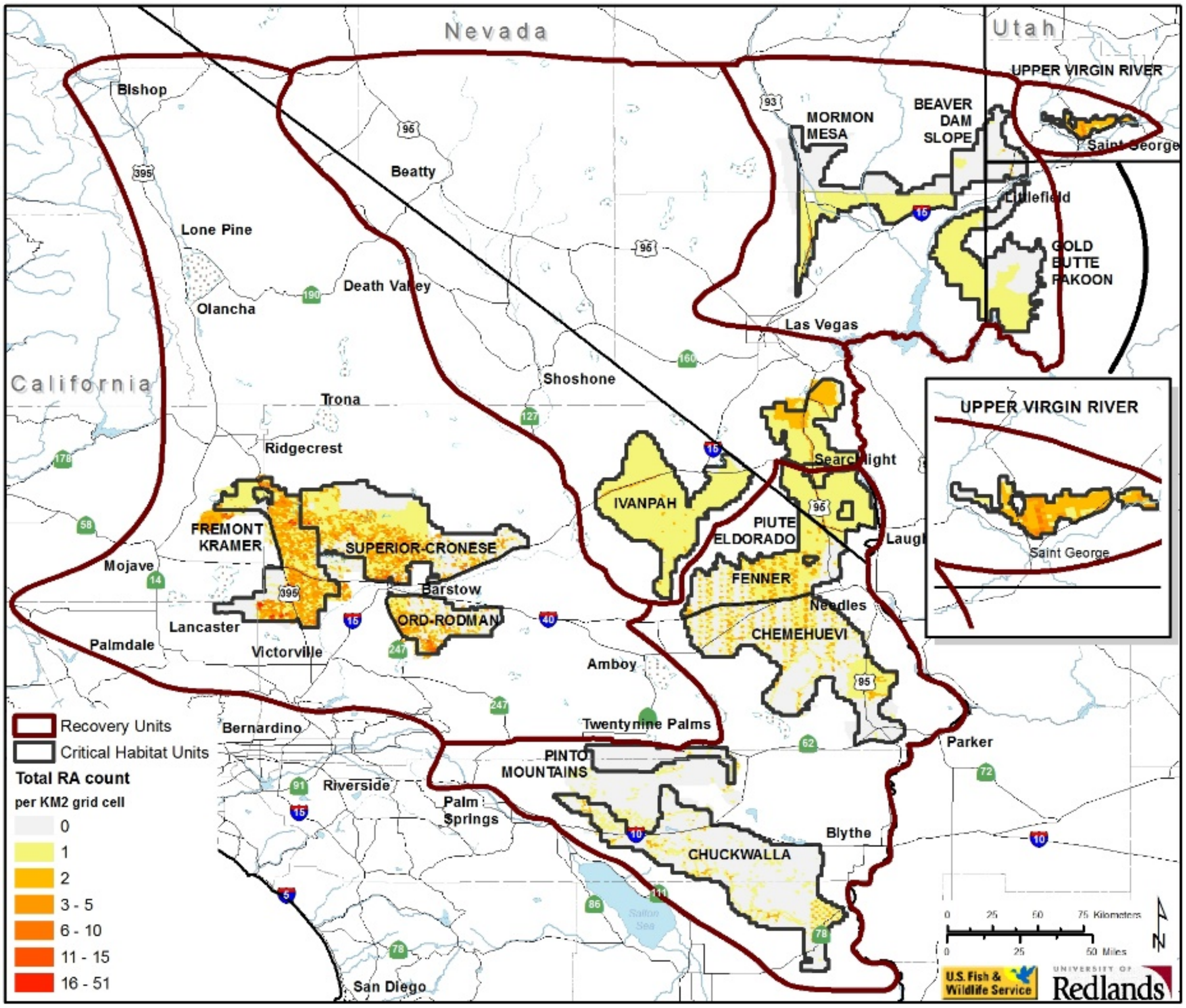


Map showing the value of the slope of the natural log of density estimates, extrapolated to the 17 TCAs.
Source: Table 4 from Allison and McLuckie (in prep.)

5.3.3 Third Investigation: Exploring Connections Between Positive Trends in Abundance and Recovery Actions

The project partners had intended as a third step to investigate the hypothesis that the positive trends reflect management actions in the TCA rather than threats. However, counts of management actions in the 2x2 km cells within each TCA (Figure 62) were primarily based on whether the land managers there had shared this information. Therefore, this third investigation was not pursued at this time. The project partners hope that the RA Tracking tools discussed in Chapters 2 and 6 will eventually yield a comprehensive database of implemented recovery actions that would form the basis for this kind of analysis.

Figure 62: Counts of Implemented Recovery Actions in the TCAs Recorded in the Desert Tortoise SDSS (as of 2014)



Map showing the number of implemented recovery actions that were reported by land manages and included in the Desert Tortoise SDSS database as of 2014. These counts showed a strong pattern of more reported actions in areas with whose management groups the Recovery Implementation Teams (RITs) had stronger relationships. While not possible currently, in future when more recovery actions have been reported and integrated into the SDSS it may be possible to return to this analysis.

Source: Desert Tortoise SDSS

5.4 Results

The results for all models created to predict the slope of the natural log of densities across the 17 TCAs are presented in Table 20.

Table 20: Results for All Models to Predict Observed Densities Across TCAs for the 7 Year Period (2004-2012)

Model ID	Model Description	r^2	df	SSE	n	Res Var	p	AICc(1,p)
M1	Risk to Tortoise	0.035	15	2561.2	17	150.65	2	37.72
M2	Agg Threat to Tortoise	0.038	15	2551.9	17	150.11	2	37.71
M10	(Sum of Population Effect Tortoise) X POP	0.518	12	1278.3	17	75.19	5	41.43
M11	Sum (Population Effects Tortoise) w/o POP	0.554	12	1184.1	17	69.65	5	41.15
M103a	Sum 3 PEs (Adult Mortality, I/E, Reproduction) w POP	0.210	13	2095.8	17	123.28	4	40.78
M102ar	Sum 2PEs (Adult Mortality, Repro) w POP	0.048	14	2524.5	17	148.50	3	39.41
M102aie	Sum 2PEs (Adult Mortality, I/E) w POP	0.102	14	2382.4	17	140.13	3	39.20
M100	1 PE (ChangeinAdultMor) w POP	0.031	15	2571.4	17	151.26	2	37.74
M101	1 PE (ChangeinRepro) w POP	0.003	15	2645	17	155.59	2	37.84
M102	1 PE (Changein Juv Mortality) w POP	0.014	15	2615.7	17	153.86	2	37.80
M103	1 PE (Change in IE) w POP	0.102	15	2382.6	17	140.15	2	37.45
M3_PPT	Mean Oct-Mar 2004-2012 Precipitation (PRISM)	0.041	15	2544.2	17	149.65	2	37.70
M4_HisFire	Mean Historical Fire attenuated by time over 100 years	0.038	15	2553.1	17	150.18	2	37.71
M5_Hum Access	Human Access layer	0.002	15	2648.5	17	155.79	2	37.84
M6_BaseAHP	Current Altered Habitat Potential	0.153	15	2246.8	17	132.16	2	37.24
M7_Hab Pot	USGS 2009 Habitat Potential	0.022	15	2594.9	17	152.64	2	37.77
M8_3Yr Density	Avg Density last 3 Years w good data	0.000	15	2652.7	17	156.04	2	37.85

Source: Desert Tortoise SDSS

For each model tested (Table 20):

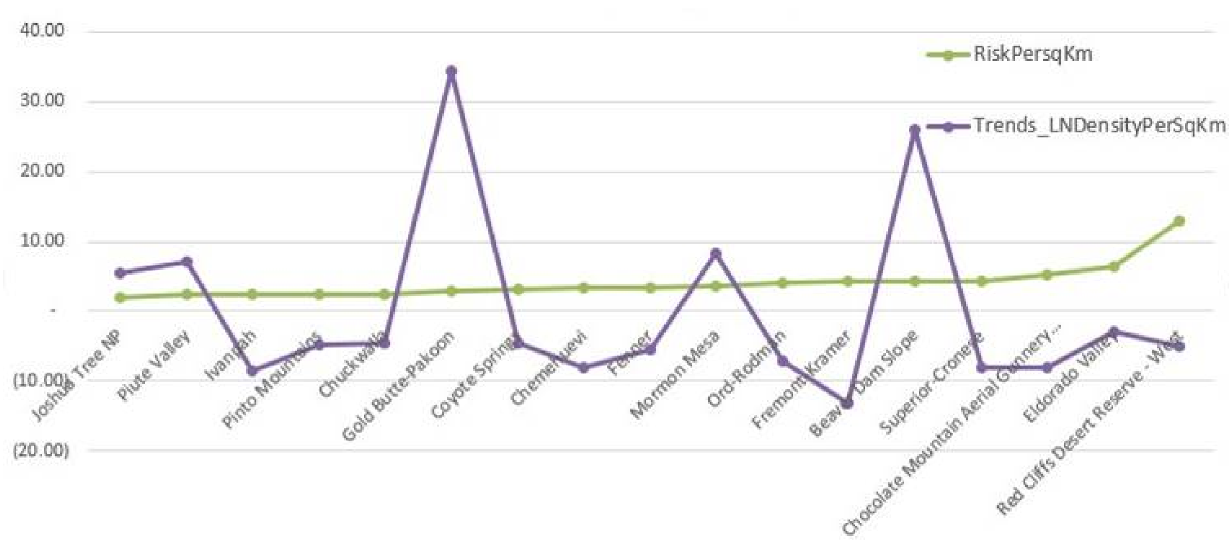
- r^2 is the standard correlation measure, the coefficient of determination
- df is degrees of freedom
- SSE is Sum of Squares for Error
- N is number of data points (17 for the 17 TCAs)

- Res Var is Residual Variance
- P-value is the number of variables in the model
- AICc(1,p) is the second-order Akaike value

The important values in this table are r^2 and AIC_c; a higher r^2 and a lower AIC_c value would suggest that the model is well fitted to explaining the observed tortoise densities. If the model perfectly explained the observed densities, then $r^2 = 1$; an r^2 value of 0.5 or greater (as in M10 and M11) is reasonably good, particularly given the challenges around desert tortoise biology and ecology. However, these two models also have a higher AIC_c value.

The model with the lowest AIC_c coefficient is M2, which is based solely on the aggregate threat output, though the model based on risk (M1), which is the product of aggregate threat times probability of presence, has almost the same AIC_c value (Figure 63). Models with AIC_c values within < 2 of each other should not be considered meaningfully different from one another.

Figure 63: Correlation of SDSS Risk Intensity With the Slope of the Log (ln) of Density Across TCAs



Graph showing correlation of the Risk Intensity output of the Desert Tortoise SDSS with the slope of the ln of observed tortoise densities across the 17 TCAs, considering all seven years of abundance data.
Source: Desert Tortoise SDSS

The results from testing the explanatory models against the average of density over the last three years when data is available in each TCA are shown in Table 21.

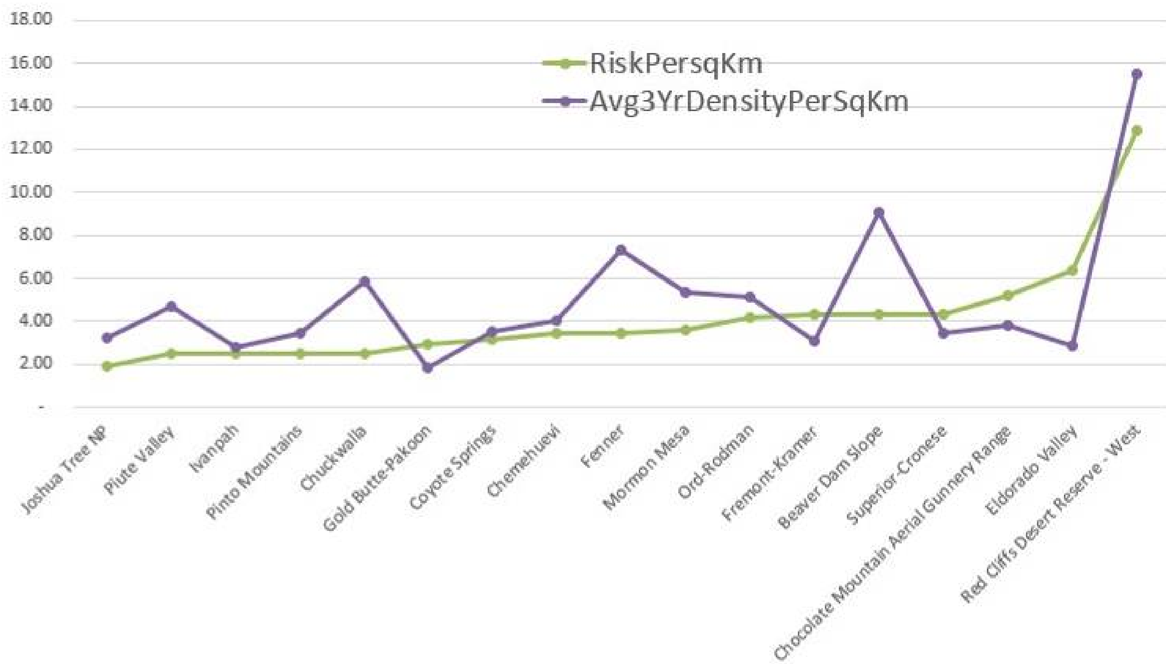
Table 21: Results for All Models to Predict Observed Densities Across TCAs Over the Last Three Years

Model ID	Model Description	r^2	df	SSE	n	Res Var	p	AICc(1,p)
M1	Risk to Tortoise	0.569	15	72.90	17	4.29	2	24.58
M2	Agg Threat to Tortoise	0.618	15	64.68	17	3.80	2	24.14
M10	Sum(Population Effects) X POP	0.777	12	37.82	17	2.22	5	28.44
M11	Sum(Population Effects) w/o POP	0.748	12	42.69	17	2.51	5	28.88
M103a	Sum 3PEs (Adult Mortality, I/E ,Reproduction) w POP	0.774	13	38.27	17	2.25	4	26.01
M102ar	Sum 2PEs (Adult Mortality, Reproduction) w POP	0.650	14	59.26	17	3.49	3	25.56
M102aie	Sum 2PEs (Adult Mortality, /E) w POP	0.773	14	38.42	17	2.26	3	23.96
M100	1 PE (Adult Mortality) X POP	0.004	14	51.83	17	3.05	2	23.32
M101	1PE (Reproduction) X POP	0.016	15	166.61	17	9.80	2	27.63
M102	1 PE (Juv Mortality) X POP	0.031	15	163.98	17	9.65	2	27.57
M103	1 PE (I&E) X POP	0.015	15	166.75	17	9.81	2	27.64
M3_PPT	Mean Oct-Mar 2004-2012 Participation (PRISM)	53.6%	15	78.53	17	4.62	2	24.86
M4_HisFire	Mean Historical Fire attenuated by time over 100 years	6.7%	15	157.95	17	9.29	2	27.44
M5_HumAccess	Human Access layer	16.8%	15	140.80	17	8.28	2	27.01
M6_BaseAHP	Current Altered Habitat Potential	13.8%	15	145.91	17	8.58	2	27.14
M7_HabPot	USGS 2009 Habitat Potential	0.6%	15	168.19	17	9.89	2	27.67

Source: Desert Tortoise SDSS

Considering just the most recent three years of density data, the model with the lowest AIC_c coefficient is M102aie which is based on a linear combination of Adult Mortality and I/E, though the model based on the core SDSS output of Risk to population alone (M1), has one of the smaller index values (Figure 64).

Figure 64: Correlation of SDSS Risk Intensity With the Slope of the Log (ln) of Density Across TCAs for the Last Three Years



Graph showing correlation of the Risk Intensity output of the Desert Tortoise SDSS with the slope of the ln of observed tortoise densities across the 17 TCAs, considering just the most recent three years of abundance data.

Source: Desert Tortoise SDSS

5.5 Discussion

In this investigation, the selected explanatory models representing the outputs of the Desert Tortoise SDSS did not sufficiently explain the changes in slope of the ln of observed tortoise density. Model M1, which uses the core system output of risk to population, has the lowest Akaike coefficient (AIC_c) of the models reviewed, indicating that it is the best fit out of all the models considered to explain the observed density. However, standard regression analysis suggests this model would only account for 3.5% of the variability.

Conversely, the two models (M10 and M11) that are a linear combination of all four Population Effects outputs of the SDSS have sample coefficient of determination (r^2) that suggest they can explain more than 50% of the variability in the signal. However, their Akaike coefficients (AIC_c) are almost 4 points higher than M1 and M2. In model M11, four variables are trying to explain one variable, using 17 data points. The higher AIC_c value indicates that this model is over-fitting the data for the sample size; with 5 degrees of freedom it is easy to over fit 17 points of data.

The best-fit parameters for M10 underline an important assumption of the design behind the SDSS conceptual model (Table 22)

Table 22: Best Fit Parameters for M10 Explanatory Model

sl_Repro	sl_JuvMor	sl_AdultMor	sl_I/M	intercept
0.405139835	-0.07012	0.014809	-0.12805	1.268587

Source: Desert Tortoise SDSS

The population effects aggregate threats that suppress reproduction, increase juvenile and adult mortality and suppress mobility. In other words, the conceptual model is a model for negative change in the population. It represents risk in one geographic area relative to another, but not relative to the past. If the intensity of contributing threats to juveniles has decreased in the last 9 years so that juveniles were surviving longer, and contributing to growth in the adult population, the SDSS output would not capture that effect,

Given that the population densities are for adult populations, and the appearance of negative weight in M10 and M11, the project team further investigated a model with just Adult Mortality and Reproduction (M102ar), Adult Mortality and I/E (M102aie), just Adult Mortality (M100) and Adult Mortality, I/E and Reproduction (M103a). In all cases the Akaike index dropped somewhat with the decrease in parameters, but the classic explanatory power of the models also fell to 10% and lower.

Finally, considering the core assumption of a decrease in population in the SDSS conceptual model, the project team excluded the TCA with a positive slope. However, this did not significantly change these results.

In terms of the models based on a single variable that is not an output of the Desert Tortoise SDSS, Altered Habitat potential (see Chapter 3) performed best. With an equivalent AICc to M1, it still only explained, in terms of correlations, 15% of the trends. That average mean precipitation had little explanatory power may not be so surprising as this was an average taken over 20 years for each TCA, so year to year variations are obscured.

5.5.1 Explaining the Average Density for the Last 3 Years

Looking at Table 21 above, at face value the Desert Tortoise SDSS models have much more explanatory power of the variability observed in the last 3-year average density across the TCAs. The risk output of the model M1 almost has the lowest Akaike index and can explain almost 60% of the variability in observed adult population density. However, the slope is positive, suggesting that the higher the threat, the larger the population, which is the reverse of the logic employed in designing the system.

The highest classic correlation (r^2) is again shown for a linear combination of all four Population Effects (M10), though examination of the derived weight parameters shows the same pattern in their signs as for this model against the slope of ln Density, and the Akaike coefficient (AIC_c) suggests over fitting. The model with the actual lowest (AIC_c) is M102aie, which is a combination of Adult Mortality and I/E, and for which adult mortality is negatively correlated with current density, and the explanatory correlation is 77%. In terms of the explanatory models based on individual data sets outside the SDSS, precipitation is the most likely to explain the observed density, explaining 56% of the variability.

A cautionary note about this exploration is the influence of the single TCA Redcliff Desert Reserve, which (see the chart in Figure 64) has a density more than 3 times the average across the TCA. The SDSS Risk intensity for that TCA is also 3 times that of the average. This single data point drives much of the positive correlation between outputs of the SDSS and the 3-year average density. Remove that single point, and the explanatory power collapses, with M102aie retaining the most at 26%. With this TCA removed, M1 becomes negatively correlated with risk, but with an explanatory power of only 7%.

Were the system estimates of current risk in an area a useful predictor of the current population density of adult tortoises in that area, this would be a most useful capability. Conceptually however, changes to threats occurring now, not including habitat destruction, should not explain existing population densities, but indicate changes that can be expected in the future.

The Redcliff Desert Reserve West TCA is the smallest TCA (11,500 hectares) and lies in the Upper Virgin recovery unit, an area with historically higher abundance, a long history of careful surveys and higher reporting of threats than in other Recovery Units. That its removal has such a major effect on all the correlation estimates for current density indicates that there are too few data points available from this abundance data set to validate these models with confidence.

5.5.2 Challenges to the Research

5.5.2.1 Temporal

There are complications to correlating trends in tortoise densities and SDSS metrics that relate to the long generation time of desert tortoises compared to the time range of the current observations and the variable time impacts of each threat. Allison and McLuckie (in prep.) estimate trends in the density of adult desert tortoises in TCAs over a 7-year period. The generation time of Mojave desert tortoises is ~ 25 years (USFWS 1994), so the shorter trends in adult numbers are attributable to change in adult survivorship and/or recruitment into adult size classes. It remains for population trends of the future (over more than a generation) to provide a measure of reproduction and juvenile survivorship since 2004. The Desert Tortoise SDSS estimates the relative impact of threats based on their predicted effect on risk to the population; threats that affect both adult and juvenile tortoises are included and variation in temporal effects of threats are not accounted for. In addition, the SDSS includes over 40 threats, 18 stresses and 4 population effects. The single trend values for 17 TCAs represent a small sample size compared to the many possible parameter subsets that could be used to generate reasonable models.

5.5.2.2 Spatial

Another consideration is the spatial scale of analysis. The abundance data of Allison and McLuckie (in prep.) is as the scale of TCA (11,000 – 400,000 hectares). At scales much below TCAs, the data begin to dissolve into individual tortoise home ranges.

At the scale of the Recovery Units (178,000 – 5,929,00 hectares), the slope of the natural log of population density has a positive correlation with Desert Tortoise SDSS Risk, but the aggregation at that scale will obscure most detail and provides little guidance for the effective location of recovery actions. At the scale of the TCA, the aggregation of threats may still obscure underlying processes that are driving change in the population. It could be that the SDSS models are operating at a finer scale than TCAs. In an investigation of the impact of drought on population, Longshore et al. (2003) reported on two sites 29km apart. That study found that local precipitation varied substantially, such that the seven-year survival rate at one site was more than 3 times than that at the other site. However, in the early part of the study, before the drought, both populations had similar survival rates.

As the gathering of abundance data continues, it may be possible to extrapolate throughout the TCAs with confidence at smaller scales, say 10km. Re-running this analysis at such scales might produce a tighter connection between the threat data in the Desert Tortoise SDSS (which is analyzed on hectare grid cells) and observed abundance. Plans are in place between FWS and the University of Arizona to produce an abundance layer at a finer resolution.

Apart from the scale at which to perform the analysis, there is also the bias inherent in restricting the analysis to TCAs only. Threat intensity varies much more over the entire range than within the TCAs. If the SDSS is able to predict risk to tortoise population, the underlying patterns might only be evident when the full gamut of threats is examined across the range, not only patterns within the areas that are relatively well-managed for tortoises.

5.5.2.3 Future Research Directions

The project team presented an earlier version of this analysis to the Desert Tortoise Science Advisory Committee (SAC) at a workshop in June 2014. The SAC members agreed with the project team that there was no apparent, simple answer as to why the Desert Tortoise SDSS model outputs provide little explanatory power of the new population trend data. The system includes all threats known in the literature, and at its crudest makes the assumption that where there are more threats, there is likely to be more of a population decline. It is possible, but not likely, that there is a missing factor in the conceptual model for threats to the tortoise. It is more probable that some of the data layers used to represent threats on the landscape are poorly defined or erroneous. For example: the system uses a disease threat intensity layer that has the same value across the entire range, in the absence of better data. Ongoing disease studies may provide a more accurate, spatially varying disease intensity layer for inclusion in the system. The same applies for all of the threat intensity layers in the system; the project team is always looking to improve on the current data inventory.

Another possibility is that the system conceptual and computational model need adjustment, as is discussed in the next section.

5.5.3 Towards a General Unified Model for Desert Tortoise Recovery

Two major, intertwined shortcomings with the current conceptual model for desert tortoise recovery are the inclusion of Immigration and Emigration using a weighted sum with the other demographic population effects and the formal disconnect (weight = 0) between those stresses that affect it, with the single exception of Population Fragmentation.

With the research conducted on population fragmentation in Chapter 3, the necessity of more accurately modeling movement across habitat areas became clear. What both the diffusion model underlying the Fraggle experiments and the meta-population model underlying the Population Capacity approach have in common is a model that formally characterizes the relationship between demographic rates for adult females and landscape habitat.

The population capacity model is based on the ability of a species to recolonize locally, as determined by the ratio of mortality rates in a territory and birth rates in neighboring territories, and the quality of the local area. Like the current Desert Tortoise SDSS, it does not explicitly require a population density, but instead looks at the capacity of the habitat.

In the derivation of the spatially explicit individual territory model (Section 3.5.2), recolonization was proportional to the birth rate, and extermination to the mortality rate of adult females. Those rates are taken as constant everywhere. In the same way that quality of habitat was spatially characterized by the average altered habitat potential (AHP) within each territory, the mortality and birth rates could also be allowed to vary by territory. The simplest implementation would be to assume that the rates have their current values from the literature, but reduced by the percentage that is the average aggregated threat for adult mortality rate and birthrate respectively, as calculated by the current Desert Tortoise SDSS for each territory.

The spatially varying fractions in the rates would alter the value of the connection matrix elements but otherwise leave the algebra the same. The population capacity metric for the range calculated this way is informed both by the habitat distribution and the threats distributions the desert tortoise faces on the landscape.

The analog to the equilibrium solution (fraction of occupied territories) for the individual territory model in Noon and McKelvey (1996) is $\widehat{p} = \mathbf{1} - \frac{\mathbf{1-s}}{\boldsymbol{b\,\lambda_{PC}}}$ for the range. Calculated locally, say within a TCA, this might play the role of a proxy for local population density. This would be worth testing against the abundance data as described in the earlier sections of this chapter.

CHAPTER 6: Improving Workflow and Usability of the System

6.1 Improving System Usability for Planners and Project Reviewers

The core of the Desert Tortoise SDSS is the capability to estimate, at all points within the range, (a) risk to the recovery of the tortoise; (b) increase to that risk that may occur if a proposed solar energy development project were to be sited within the range; and conversely, (c) decrease in risk that a proposed mitigation package of management actions might produce. A key objective of this project is to make all of these capabilities available online for project proponents, management agencies, other planners and reviewers, regulators and researchers. System data, models, and computations were improved through this project to better facilitate typical workflows that these users might follow.

As part of the first Energy Commission project, the partners developed an online Desert Tortoise Recovery Portal (Murphy et al. 2013). That version of the portal included three components providing access to the system data, models, and analyses:

1. The Data Explorer, which provides an online mapping interface for exploring and accessing to GIS datasets in the system, and supports data acquisition and validation efforts (http://www.spatial.redlands.edu/dtro/dataexplorer).
2. The Model Explorer, which provides an interactive interface for users to explore the conceptual model, investigate its influence on system calculations, and better understand how these results are interpreted in decision making (http://www.spatial.redlands.edu/dtro/modelexplorer; see also Section 1.3.3 above).
3. An early version of a Solar Project Impacts and Mitigation Calculator (Calculator), that provided a workflow and toolset for estimating the direct and indirect impacts of large-scale solar development projects on the tortoise. Risk reduction values of management actions had to be calculated using offline scripts, and then uploaded to the web by the project team.

Along with several aesthetic and usability enhancements, the primary feature enhancements in the second project extended this workflow so that users can define, refine, or upload proposed recovery actions associated with a mitigation package, and the system will promptly estimate the potential benefits of the package to the tortoise population. These enhancements resulted in the creation or integration of three new components: the Recovery Action Tracking and Recovery Action Designer tools; and a Risk Reporter tool. All the new data, analyses, and improvements to the system described in this report are accessible through the updated Desert Tortoise Recovery Portal at: http://www.spatial.redlands.edu/cec/.

6.1.1 Data Management and Updates

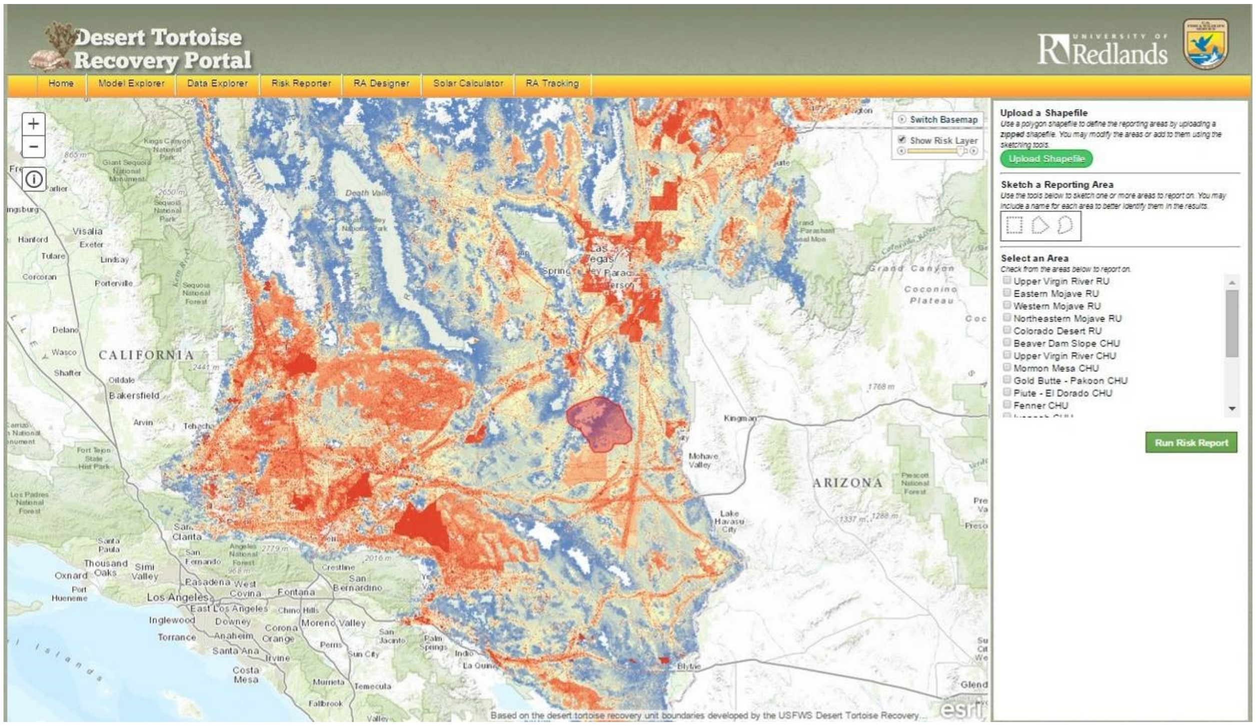
Efforts to collect, assess, document, manage, and curate the spatial data used in the Desert Tortoise SDSS have been ongoing to ensure that the system employs the most current and accurate data available. These spatial datasets inform the system calculations, and ultimately the decision maker, about where threats exist and to what degree that threat location contributes to tortoise population decline. When the spatial extent of a threat is missing, or its intensity is misunderstood or misinterpreted, the calculations and results can be affected across the range. While it may not be possible to have complete and accurate data for all of the threats included in the system, the project partners are committed to using the best available data for system calculations. Appendix A provides a complete inventory of data in the Desert Tortoise SDSS. Appendix C provides further detail on additions and updates to system data, including data and metadata development, completed as part of this project.

6.1.2 New Tool Integration

As described in Section 2.4, the Recovery Action Designer and Tracking tools integrated as part of this project provide a mechanism for creating, sharing, and accessing recovery and mitigation action information. These tools allow users to sketch or upload designs for site-specific recovery actions. In addition, the Recovery Action Designer tool calculates the risk reduction each action would produce, and makes this information available for inclusion in mitigation packages. Both the Designer, developed under this project, and the Tracker, developed with separate funding from USFWS, have been incorporated into the overall architecture of the Desert Tortoise Recovery Portal.

A new *Risk Reporter* tool permits the user to sketch an area polygon (such as a tortoise conservation area, potential solar energy development site footprint, or potential recovery action location), and then interactively review the risk results to better understand what threats, stresses and population effects are contributing to risk within that exact area (Figure 65).

Figure 65: Risk Reporter Online Tool: Selecting an Area of Interest

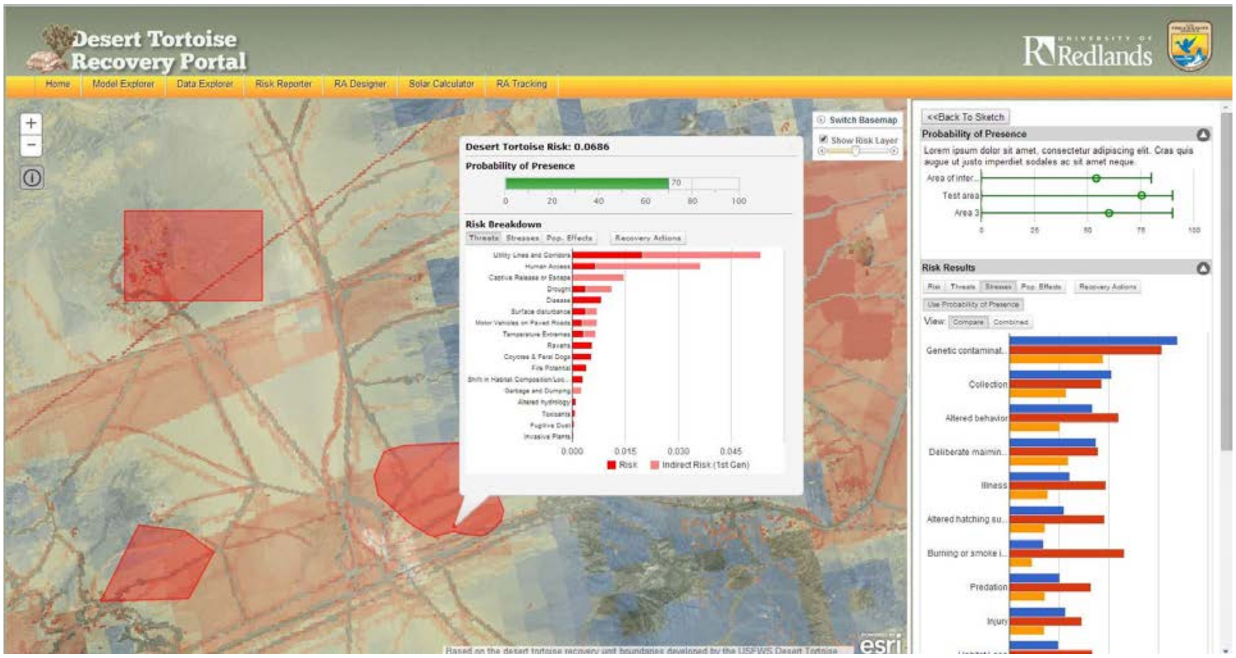


The Risk Reporter tool dashboard (at right) allows users to upload a shapefile, sketch (as in the red polygon), or select a recovery unit or critical habitat unit, as the area for running the risk report.

Source: Desert Tortoise Recovery Portal

This capability was made possible by a new infrastructure for storing and efficiently utilizing risk estimates and new methods for querying, aggregating, and summarizing the data. It is very useful for understanding what threats are driving risk in any given area. Previously, these types of reports could take hours to generate (depending on the size of the area(s) of interest); the Risk Reporter now provides access to these same results in seconds, in an interactive format that promotes exploration of the geographic data and statistical results (Figure 66).

Figure 66: Risk Reporter Online Tool: Display of Model Results



Aggregate statistical model results for the risk calculation display in the dashboard (at right) of the Risk Reporter tool. Popup windows display the factors contributing to risk at a given location.

Source: Desert Tortoise Recovery Portal

6.1.3 User Workflows

In designing and revising the architecture of the Desert Tortoise SDSS, and the Desert Tortoise Recovery Portal, the project partners considered several distinct user workflows (use cases). The most central workflow guides users in preparing spatial data sets for the calculation of impacts related to spatially-explicit solar energy projects and their mitigation packages. However, the team recognized that there are other complex tasks that need to be performed to maintain the SDSS, and to enable system outputs to be used to their fullest in support of species recovery, both for the Mojave desert tortoise and other at risk species. The project team identified five primary workflows, each supporting a specific use case for the SDSS. Only the first workflow, which related to the primary objective of this project, is presented in detail here in the main document. The other four workflows are discussed in more detail in Appendix C.

1. A solar energy project designer or reviewer has a project location in mind and is interested in developing a mitigation package that may reduce projected impacts. This user uploads a project footprint and related recovery or mitigation action information. This user can then employ the Solar Project Impacts and Mitigation Calculator to review potential project impacts and the Recovery Action Designer to define and designate site-specific actions. The Calculator can then be used to compare the increase in risk from the proposed project and reduction in risk from the specific recovery actions for mitigation.

2. A land or wildlife manager, scientist, or stakeholder may desire to further explore the spatial nature of current risks to the population and how recovery actions included in a proposed project mitigation package may affect these risks. This user could employ the new Risk Reporter tool to investigate which threats, stresses, and population effects are contributing to risk within a particular area. This information can help these users evaluate what recovery action may be most appropriate where and whether areas where proposed recovery actions have been placed will be effective.

3. Land managers can use the Recovery Action Tracking tool and Recovery Action Designer (Section 2.3; Figures 2.4 and 2.5) to specify the descriptions, locations, and extents of recovery actions being implemented on the ground. These tools allow users to specify recovery actions on the landscape, and describe these in relation to the recovery action types included in the desert tortoise Recovery Action Plan. Once a recovery action is saved in the database, it is available to other users for inclusion in mitigation packages.

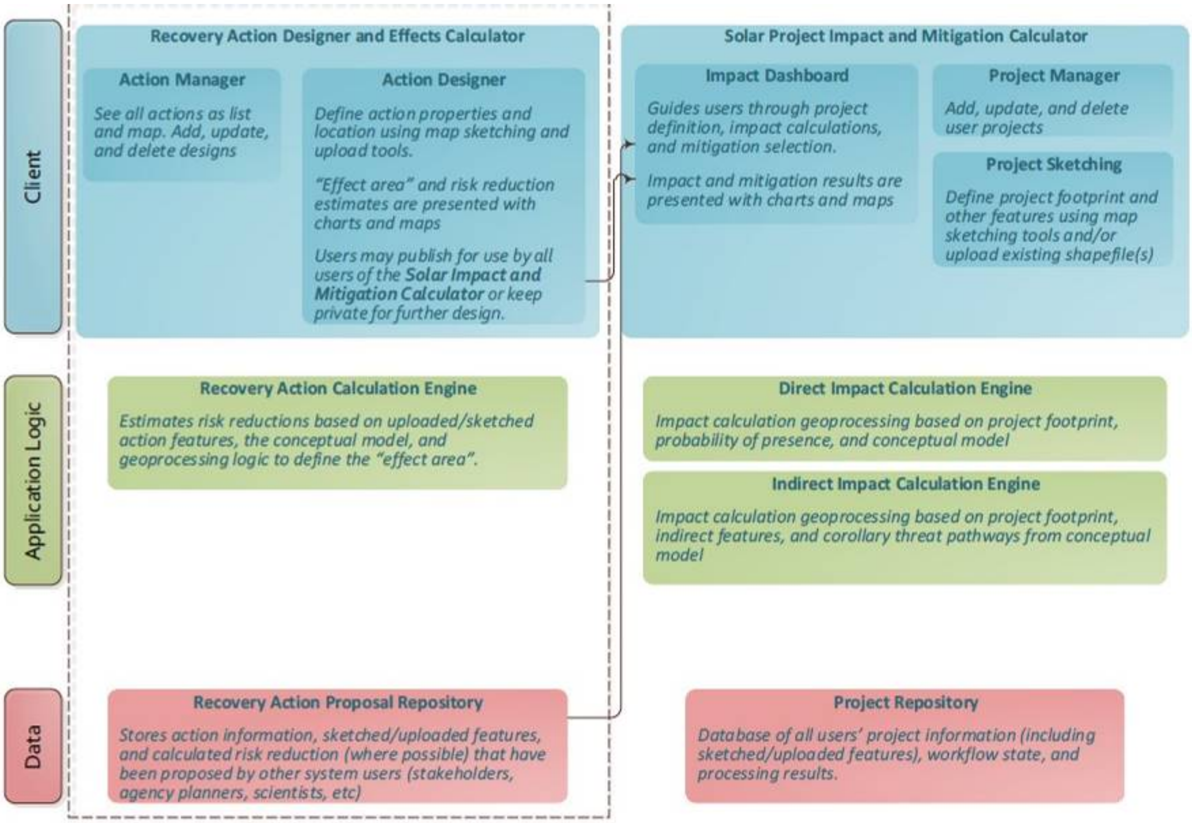
4. The project team uses the Data and Model Explorer to publish ongoing data and model updates and gather feedback and suggestions from the desert tortoise community. These updates may include revisions to datasets and the conceptual model suggested by experts or from current literature, as well as back-end revisions and enhancements to system components. This is an important and iterative process of system maintenance.

5. The Conceptual Model manager and the SDSS engine can be used by scientists, managers, or other stakeholders to develop a conceptual model and run system calculations for energy development project impacts on species other than the desert tortoise. The project partners deliberately designed the SDSS and the Portal web services to facilitate the adaptation of this entire architecture for recovery of other species of interest, particularly other desert species such as the Mohave ground squirrel (*Xerospermophilus mohavensis*) for which many of the spatial datasets would overlap with those already used for the Mojave desert tortoise. This is the primary reason why the conceptual model at the core of the system employs the well-accepted, general lexicon for conservation biology articulated by Salafsky et al. (2008). Furthermore, the system models could be adapted for other forms of energy development of interest in the Mojave Desert (wind, geothermal, etc.).

6.2 Revised Architecture for the Desert Tortoise Recovery Portal

In order to support the user workflows described above, the project team revised and restructured the architecture of the Desert Tortoise SDSS and its user-facing Portal (Figure 67). As noted in Section 6.1.2 above, a significant gain was the addition of the recovery action database and related tools (Recovery Action Designer and Tracking tool) in order to make recovery actions available and calculable for inclusion in mitigation packages. More technical detail on these revisions is provided in Appendix C.

Figure 67: Architecture of the Revised Desert Tortoise Recovery Portal



An illustration of the architecture for the expanded Desert Tortoise Recovery Portal. The dotted silo represents the components added as part of this project.

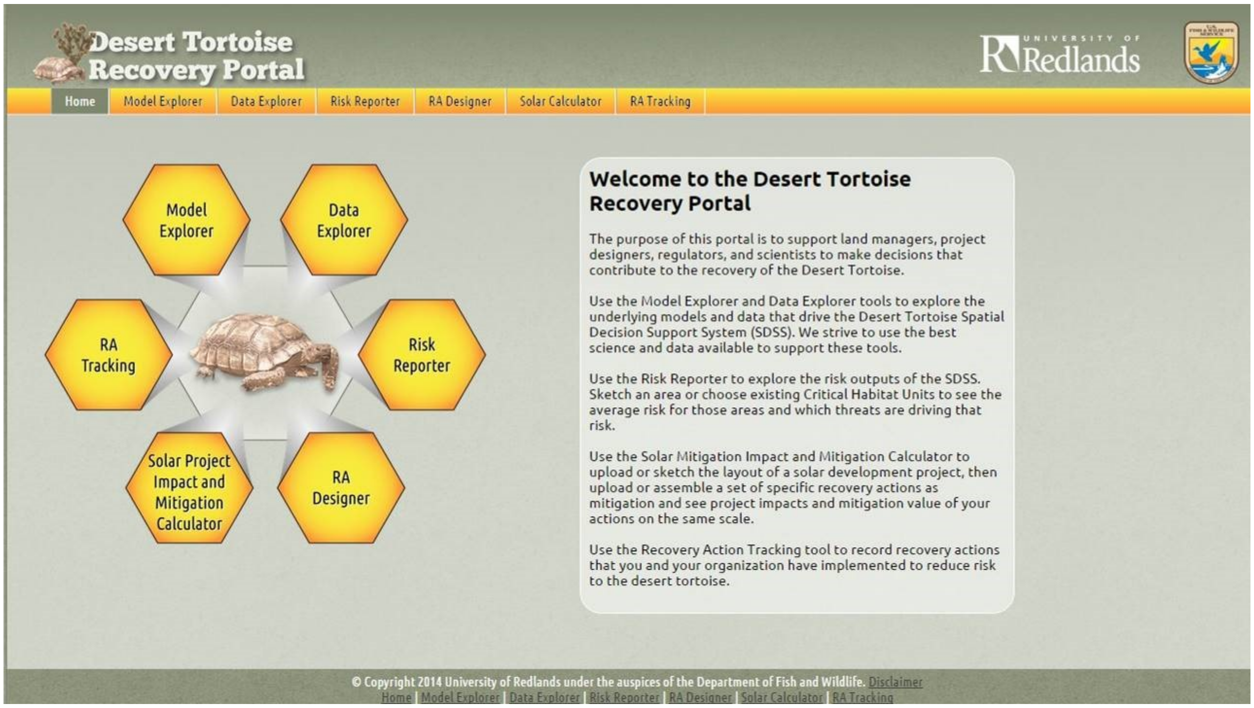
Source: Desert Tortoise Recovery Portal

6.3 Example Workflow for Desert Tortoise Recovery Portal: Solar Energy Project Designer or Reviewer

This section present a walkthrough of the revised portal and its various components, from the perspective of a designer or reviewer of a solar energy project, as in the first user workflow (use case) described in Section 6.1.3. The process for other user workflows is described briefly here, and in further detail in Appendix C.

All workflows would start at the portal home page (Figure 68), which provides a single entry point to the various tools and resources developed by the project partners for the Desert Tortoise SDSS. This page also provides an option to login and create a session that spans across the various tools and sites in the portal.

Figure 68: Desert Tortoise Recovery Portal: Home Page



Revised home page of the Desert Tortoise Recovery Portal.

Source: Desert Tortoise Recovery Portal

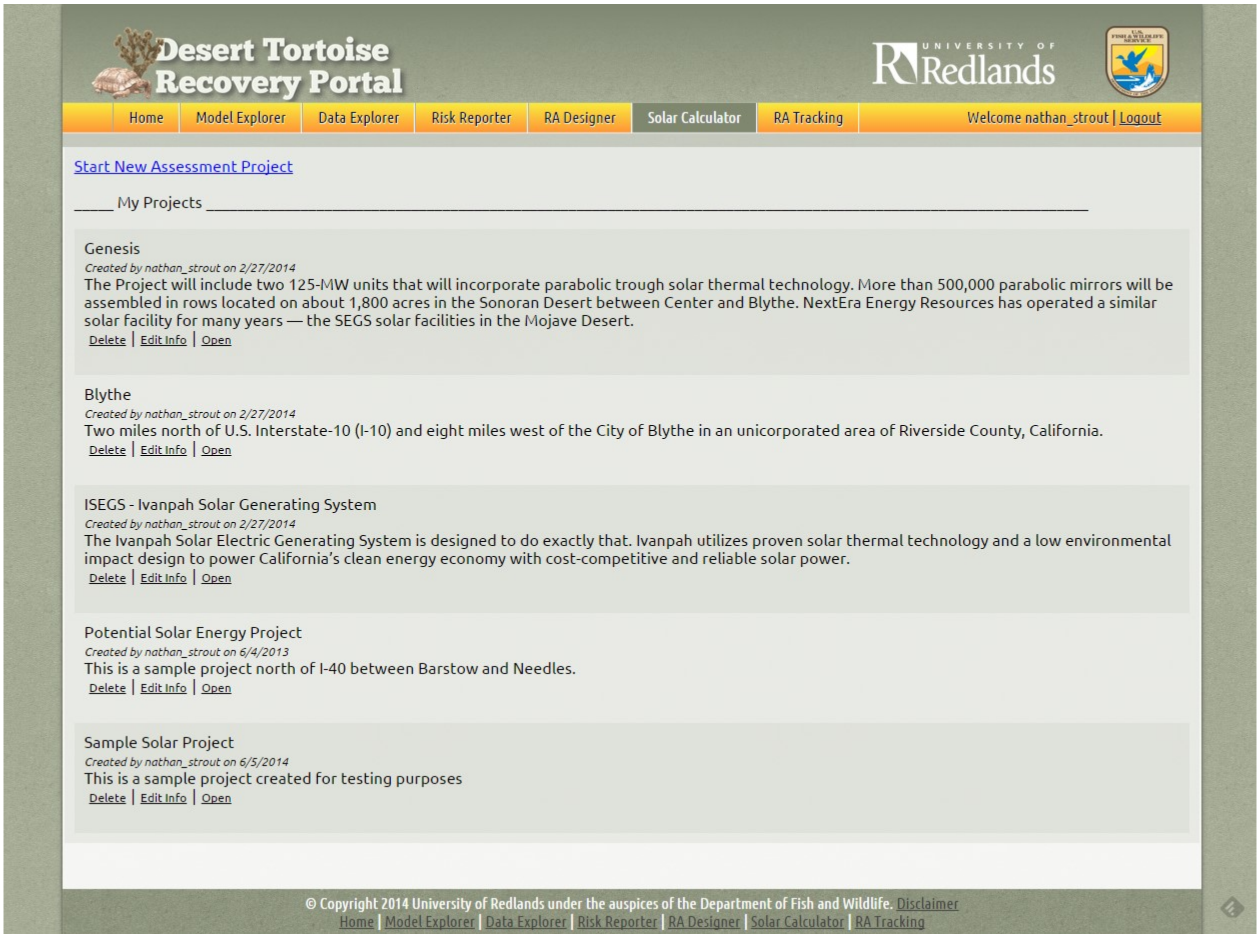
6.3.1 The First Use Case: Solar Energy Project Designer or Reviewer

The revised Solar Project Impact and Mitigation Calculator provides a workflow and toolset to estimate both large-scale solar energy development project impacts to the desert tortoise as well as potential mitigation benefits to the population as the result of proposed management actions. This section provides a step-by-step illustration of how a project designer or reviewer might use the tools in the portal to accomplish this workflow.

6.3.1.1 Project Manager

In the Project Manager screen (Figure 69), the user chooses whether to (a) create a new project assessment or (b) review, continue, or modify an existing project assessment in the system.

Figure 69: Recovery Portal: Project Manager Screen



From the Project Manager screen within the Desert Tortoise Recovery Portal, users can choose to review or edit existing projects, or to create a new assessment project.

Source: Desert Tortoise Recovery Portal

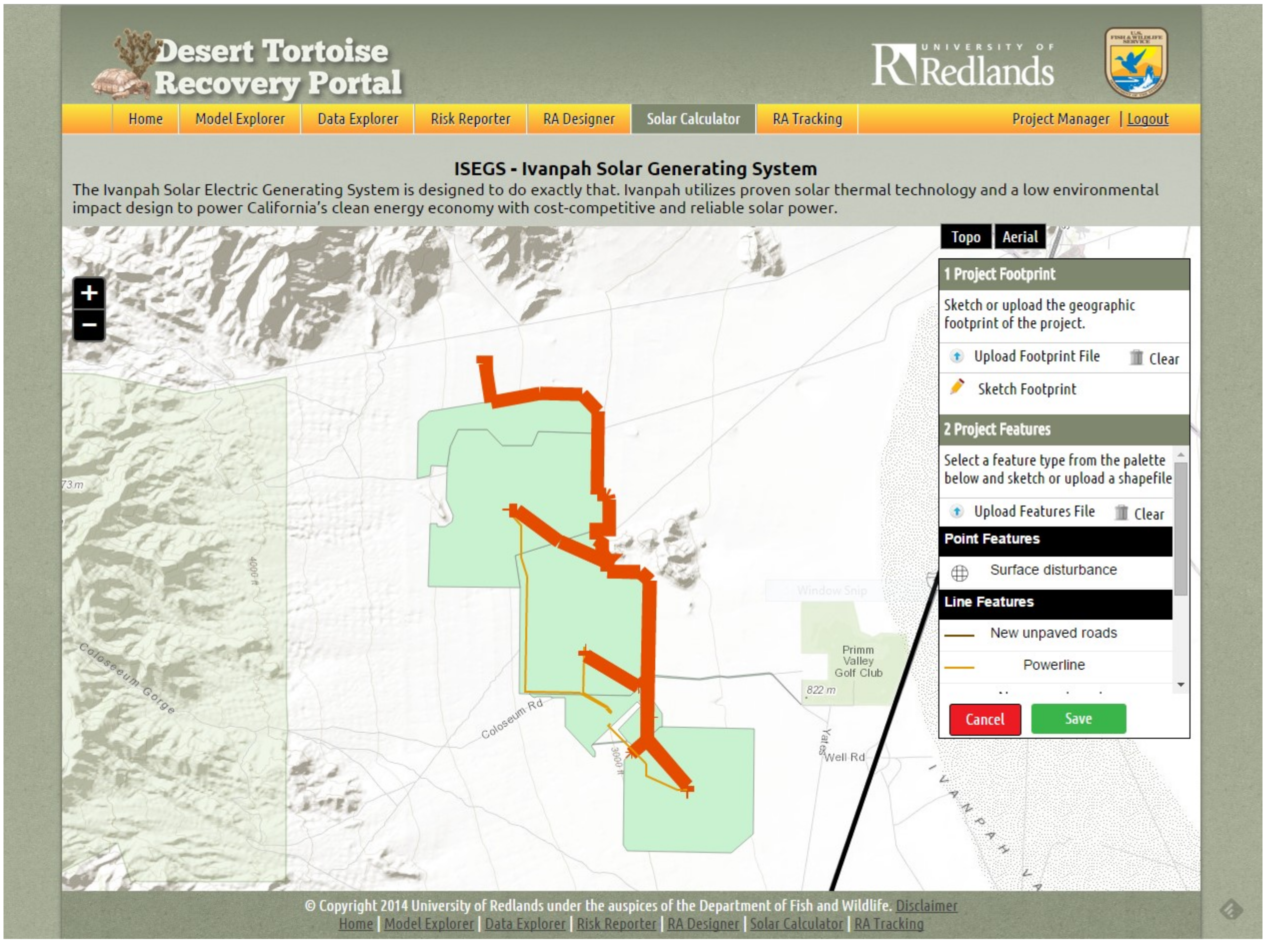
6.3.1.2 Assessment Dashboard

The Assessment Dashboard walks the user through five steps to complete an assessment. The steps include: (1) Solar Project Definition, (2) Solar Project Impact Assessment, (3) Management Actions Definition, (4) Mitigation Assessment, and (5) Assessments Comparison.

Step 1: Solar Project Definition

The first step is to spatially define the solar energy development project using an interactive mapping tool (Figure 70). The solar project footprint and any other project-related features that pose a risk to the tortoise (e.g., access roads, utility lines, additional areas of surface disturbance) may be either uploaded from a shapefile or sketched directly on the map using a sketching palette. These features may be modified at any point in the workflow and the assessment rerun.

Figure 70: Assessment Dashboard, Step (1): Solar Project Definition

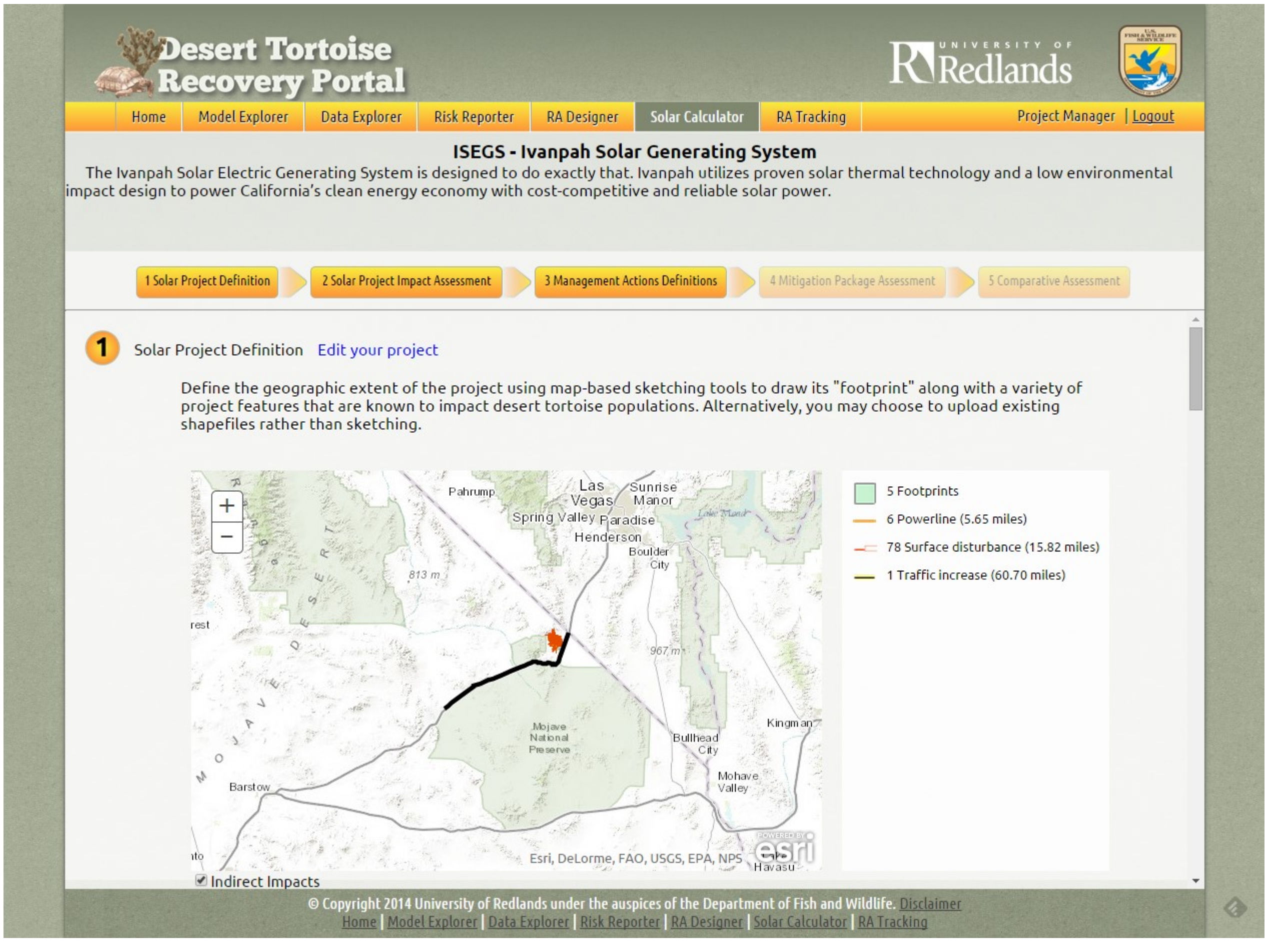


In the first step of the project Assessment Dashboard, the user defines the spatial footprint of the proposed project on the interactive map. The project footprint and related features can be sketched or uploaded as shapefiles. The user can return to this dashboard at any point in the workflow to edit these project features and rerun the assessment process.

Source: Desert Tortoise Recovery Portal

Once the project definition is saved, the user returns to the dashboard, where maps of the project are re-displayed for review (Figure 71). The SDSS engine automatically calculates the impact of the project on the desert tortoise population, and when complete, displays this information in the Impact Assessment section of the screen.

Figure 71: Assessment Dashboard, Step (1): Map of Defined Solar Project



Once the spatial footprint and features of the project are defined, the project re-displays in the Assessment Dashboard for visual review by the user.

Source: Desert Tortoise Recovery Portal

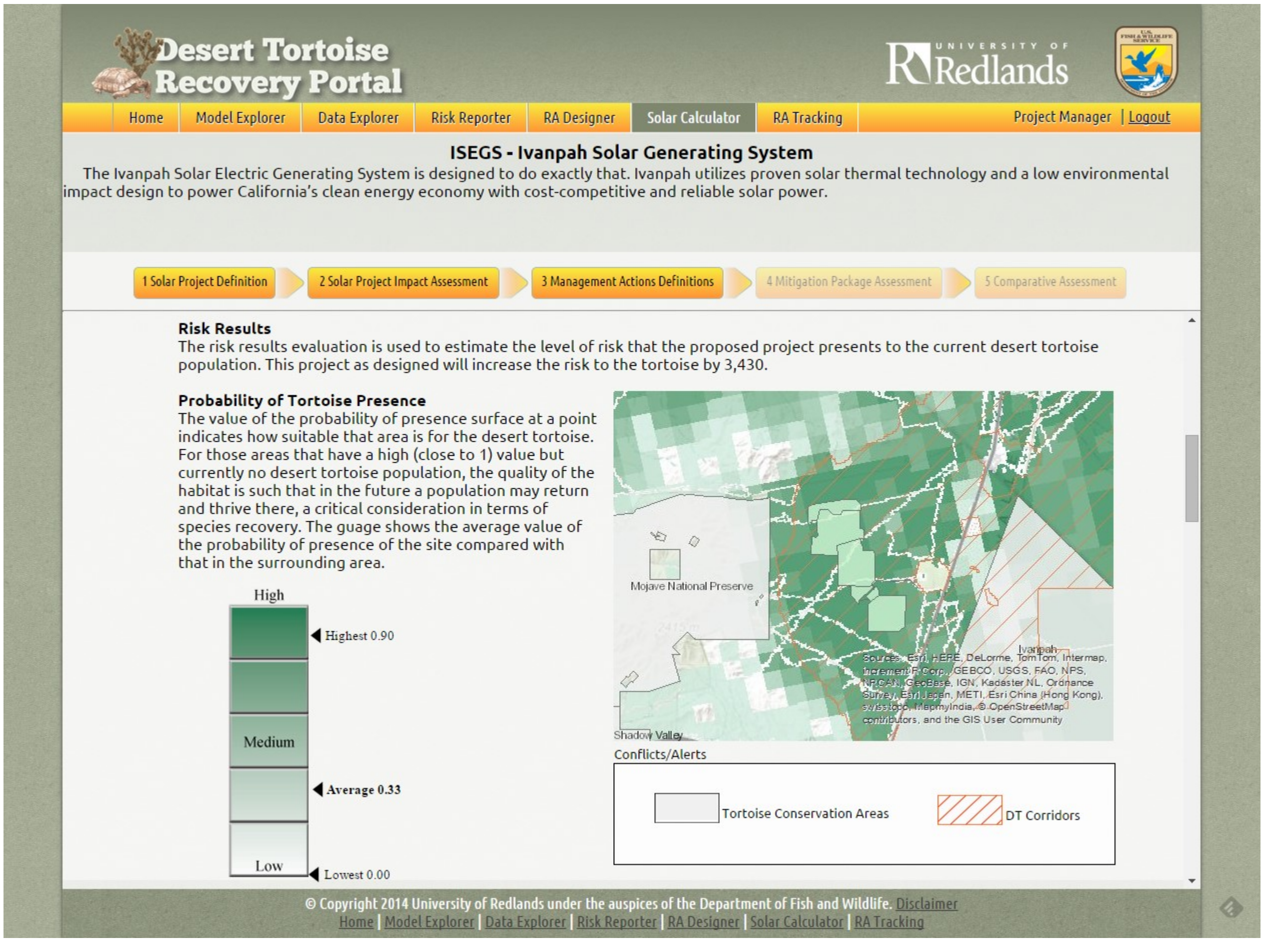
Step 2: Solar Project Impact Assessment

The impact assessment is comprised of two parts: direct and indirect impacts. The direct impact assessment evaluates the increase in risk due to threat of solar energy project itself while the indirect impact assessment evaluates the increase in risk due to other threats that may be introduced or increased due to the solar energy project as delineated in the conceptual model (e.g., roads, ravens, dust, traffic, etc.).

Probability of Presence

Because one of the primary factors in the impact assessment is the probability of desert tortoise presence, a graph and map are displayed to illustrate the habitat quality within the vicinity of the proposed project (Figure 72). A project proposed in an area with higher probability of presence will result in greater impact to the tortoise than a comparably sized project in an area with lower probability of desert tortoise presence (Murphy et al. 2013).

Figure 72: Assessment Dashboard, Step (2): Results Map of Probability of Presence for Defined Project



The first display in the Solar Project Impact Assessment workflow shows the results for probability of tortoise presence in the defined solar project area. A solar project in an area with higher probability of tortoise presence will have higher impacts than one in an area with lower probability of presence.

Source: Desert Tortoise Recovery Portal

The developer might use the probability of presence map to adjust the location of their site to an area with lower probability of presence values, which will likely reduce the impact of the solar energy project on the desert tortoise, an improvement that can be tested by rerunning the system for the new location.

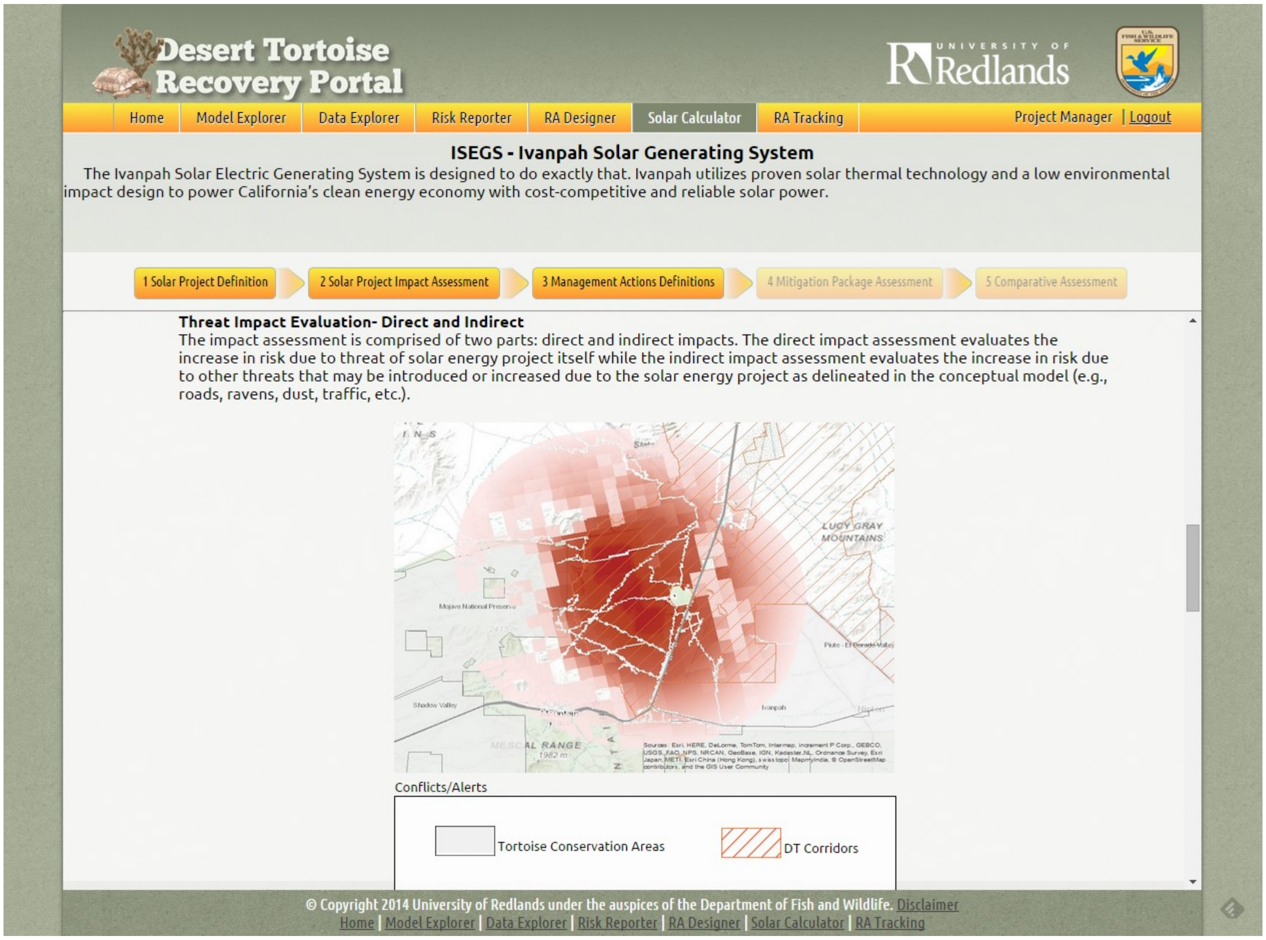
Impact Assessment

The SDSS engine generates maps and statistics that are displayed to the user in the Impact Assessment section (Figures 73 and 74).

- An impact map illustrates where the population is expected to be most impacted through both direct and indirect impacts, using a red gradient (more red = more impact; Figure 6.9).

- A single stacked bar graph shows the direct and indirect impact scores and graphically illustrates the overall ratio of direct to indirect impacts.
- A bar graph displays the breakdown of the overall increase in risk to the population. The left side shows the breakdown of the direct impact, and the right displays the breakdown of the indirect impact. The user has the option to display the breakdown by threats, stresses, or population effects (as defined in the conceptual model; Figure 6.10).

Figure 73: Assessment Dashboard, Step (2): Results Map of Threat Evaluation



Map showing results of the threat impact evaluation related to defined solar project. Areas where the tortoise population is expected to be most impacted by direct and indirect threats are darker red.

Source: Desert Tortoise Recovery Portal

Figure 74: Assessment Dashboard, Step (2): Results Graphs From Threat Evaluation

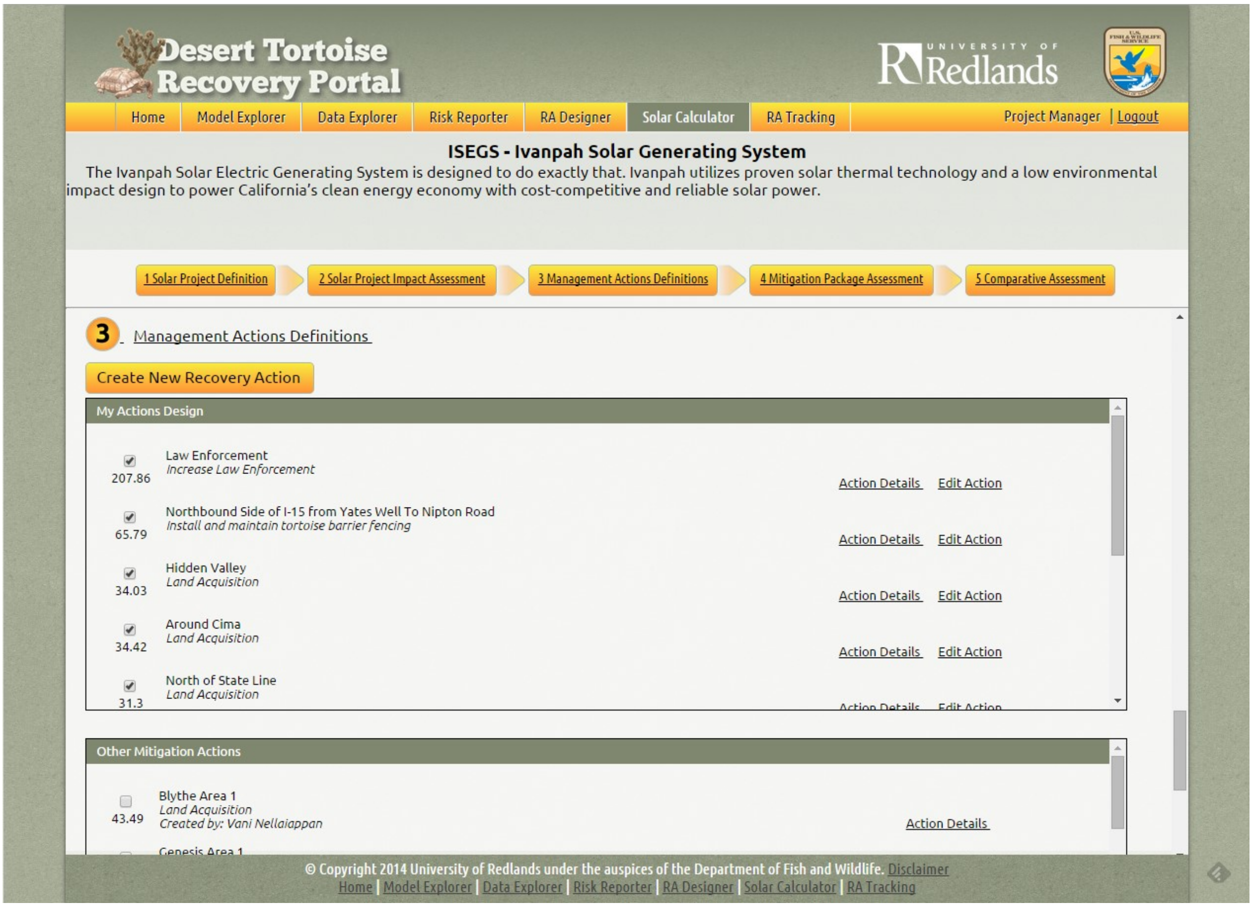
The two bar graphs display the direct and indirect impact results for the defined solar project. The top, stacked graph shows the values for, and ratio of, direct to indirect impacts. The lower bar graph shows the contribution of direct (left) and indirect (right) impacts.

Source: Desert Tortoise Recovery Portal

Step 3: Management Actions

Step 3 provides tools for the user to either select from management actions that have been previously defined in the Recovery Action Designer, or define new actions. Previously defined actions may have been created by the current user or by other users that have chosen to make their action available to all users. This currently includes the 800+ recovery actions gathered from the RIT members as described in Section 2.4.1. Because these actions have already been processed and analyzed by the SDSS, their risk reduction scores are displayed to help prioritize available actions. Alternatively, a button "Create New Recovery Actions" is provided to navigate to the Recovery Action Designer to define a new management action by either sketching or uploading footprints and features (Figure 75).

Figure 75: Assessment Dashboard, Step (3): Selecting Management (Mitigation) Actions



Users can define new management actions, or select from those previously defined in the Recovery Action Designer, in developing a mitigation package. The Desert Tortoise SDSS currently includes some 800+ recovery actions defined by the Recovery Implementation Teams (RITs).

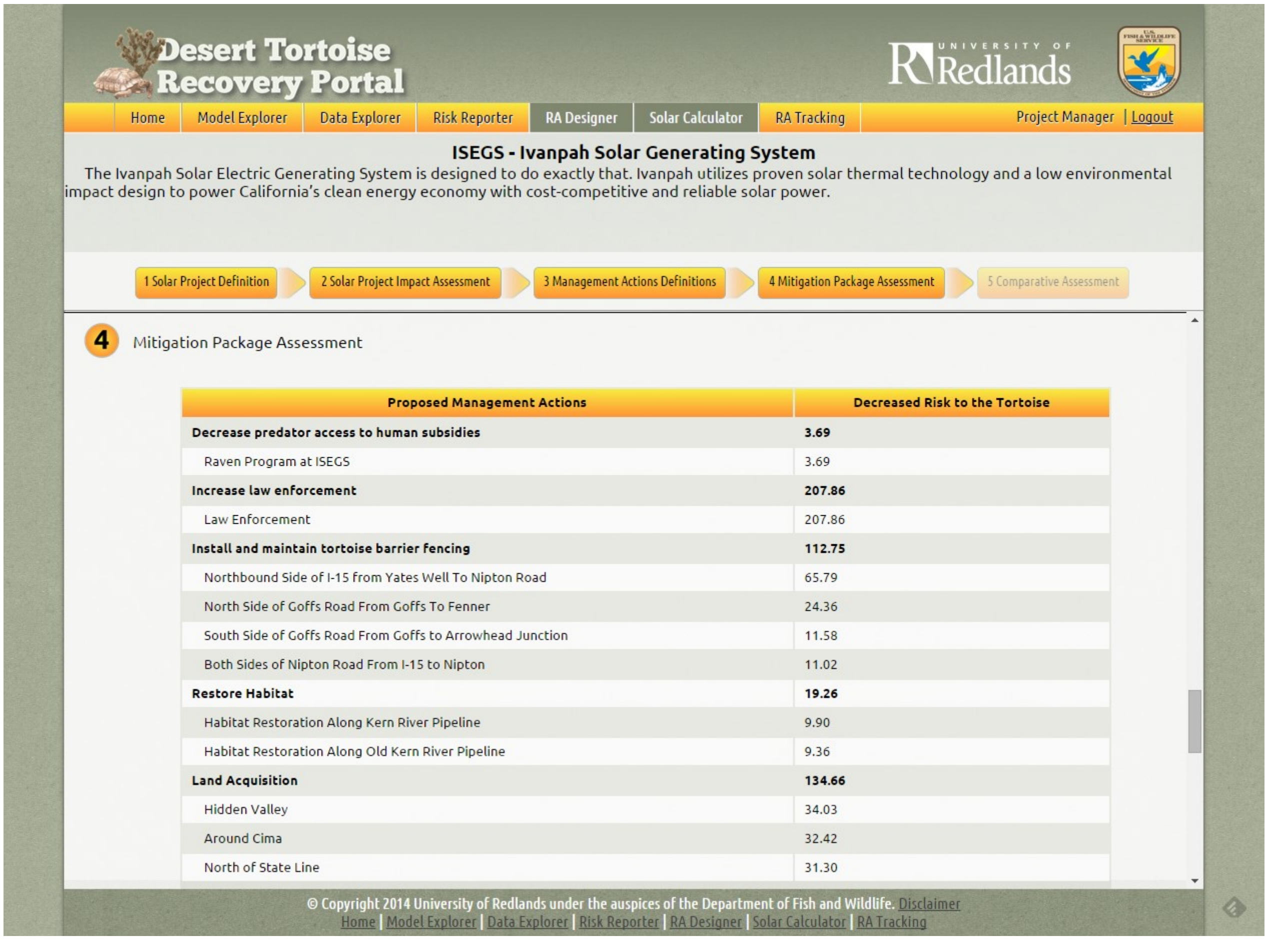
Source: Desert Tortoise Recovery Portal

Step 4: Mitigation Package Assessment

Step 4 displays a detailed assessment of the selected actions in the proposed mitigation package (Figures 76 and 77). A map displays the locations of the selected actions.

- A table of individual action risk reduction scores summarized by recovery action type is displayed to help prioritize actions in the package (Figure 76).
- An analysis of each action's scores broken down by stresses and population effects as defined by the conceptual model is displayed as a bar chart (Figure 77).

Figure 76: Assessment Dashboard, Step (4): Mitigation Package Assessment, Table of Risk Reduction

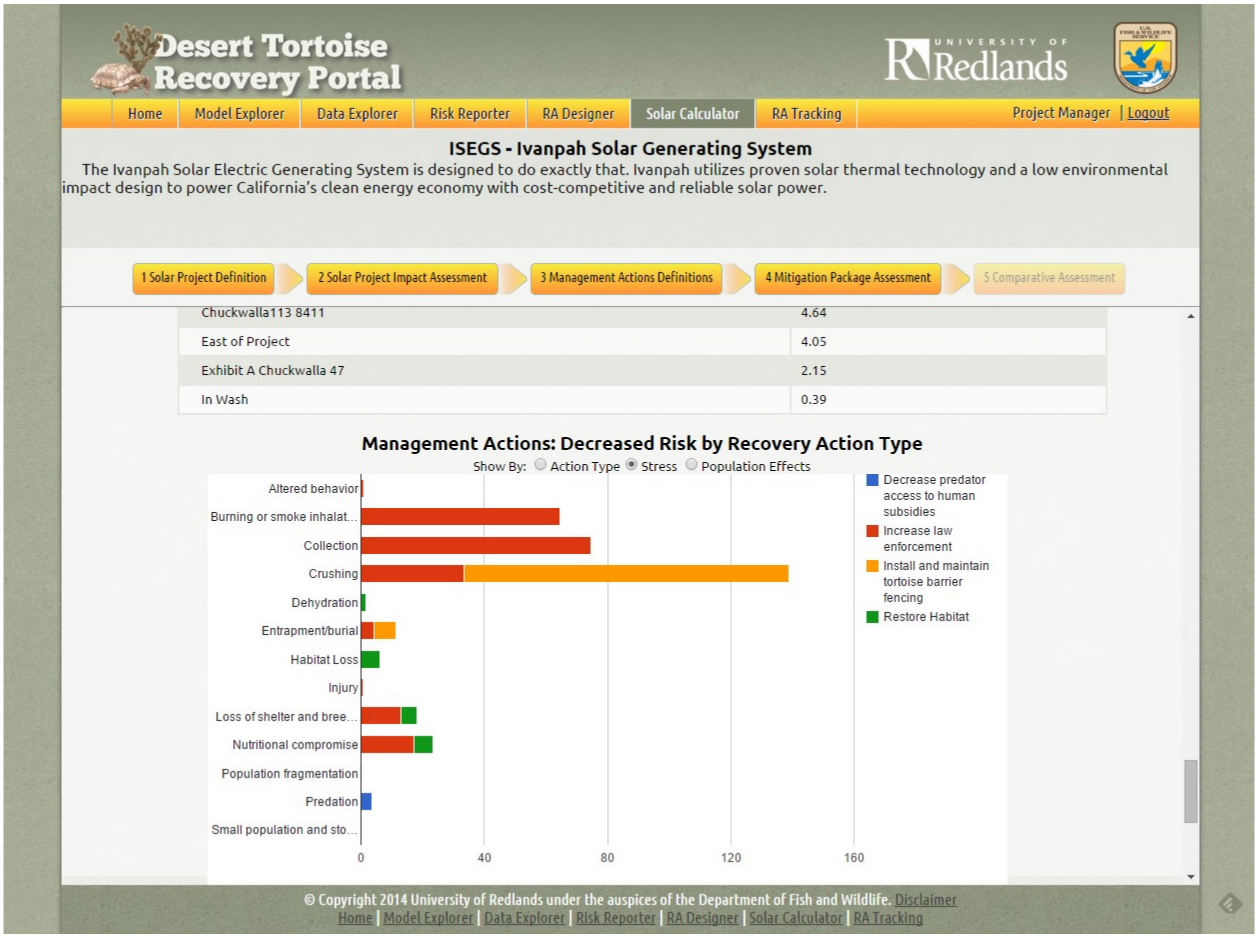


Proposed Management Actions	Decreased Risk to the Tortoise
Decrease predator access to human subsidies	**3.69**
Raven Program at ISEGS	3.69
Increase law enforcement	**207.86**
Law Enforcement	207.86
Install and maintain tortoise barrier fencing	**112.75**
Northbound Side of I-15 from Yates Well To Nipton Road	65.79
North Side of Goffs Road From Goffs To Fenner	24.36
South Side of Goffs Road From Goffs to Arrowhead Junction	11.58
Both Sides of Nipton Road From I-15 to Nipton	11.02
Restore Habitat	**19.26**
Habitat Restoration Along Kern River Pipeline	9.90
Habitat Restoration Along Old Kern River Pipeline	9.36
Land Acquisition	**134.66**
Hidden Valley	34.03
Around Cima	32.42
North of State Line	31.30

The Mitigation Package Assessment section provides information on how selected management actions may decrease the risk to the tortoise population. The table displays risk reduction for each individual action.

Source: Desert Tortoise Recovery Portal

Figure 77: Assessment Dashboard, Step (4): Mitigation Package Assessment, Graph of Risk Reduction



The bar graph in the Mitigation Package Assessment section illustrates the contribution of selected management actions to decreasing risk to the tortoise population. Users can display the results by management action type, by stress to the population, or by population effects, as defined in the conceptual model (Figure 1.3).

Source: Desert Tortoise Recovery Portal

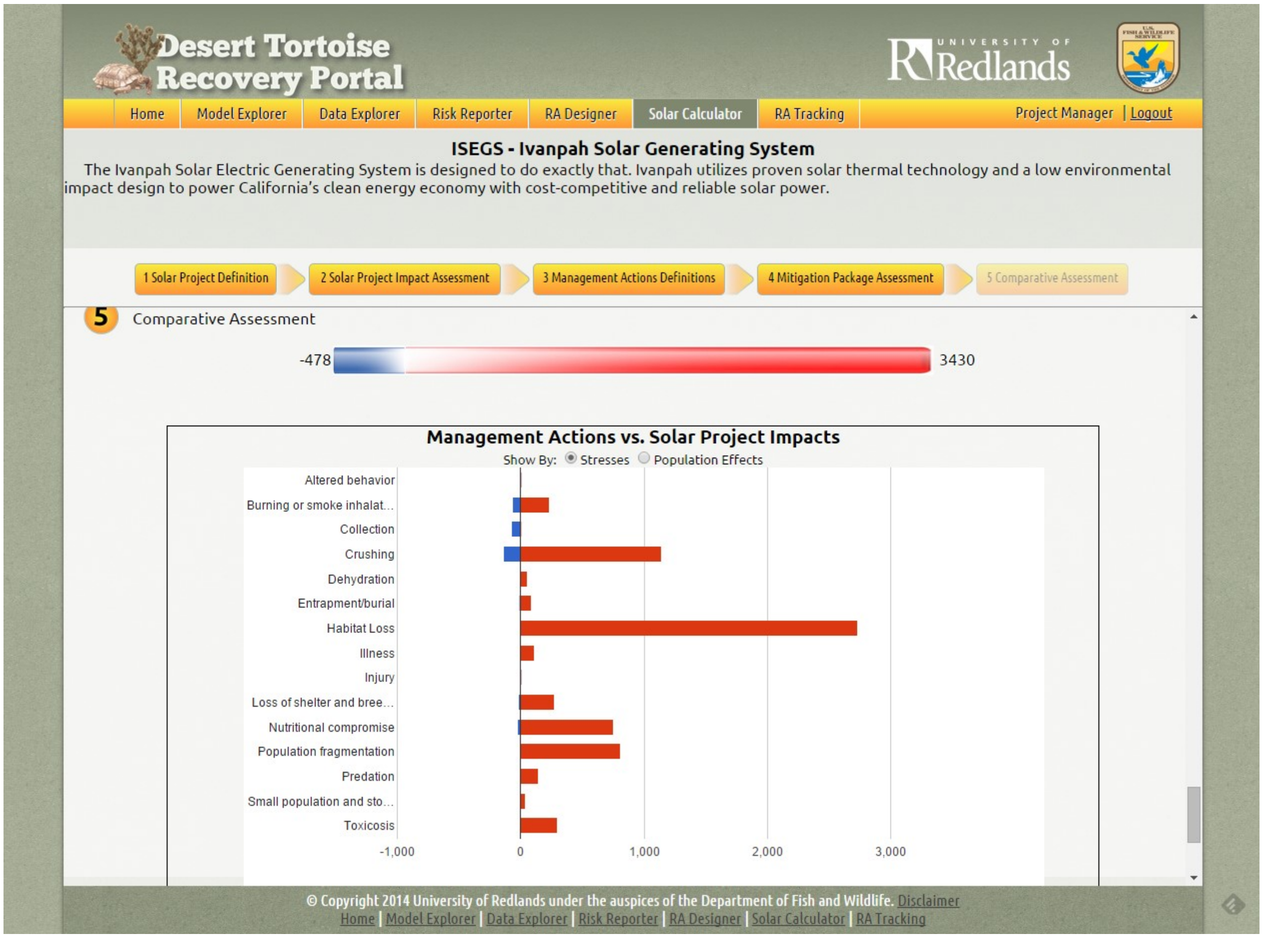
Step 5: Comparative Assessment

The final step in this workflow reviews both the increase in risk as evaluated by the impact assessment and the decrease in risk as evaluated by the mitigation assessment on the same scale. This gives the user a head-to-head comparison of the results to estimate the net change in risk to the population due to the project and its associated mitigation package (Figure 78).

- A single bar graph split by impacts (in red) and mitigation (in blue) is displayed to illustrate the net change in risk from the proposed project and mitigation package.
- A bar chart breaks the comparison of impacts and mitigation actions down by either stresses or population effects.

Finally, a link is provided that allows the user to generate a report template in Microsoft Word containing the text, tables and graphs displayed in the Solar Calculator Dashboard.

Figure 78: Assessment Dashboard, Step (5): Comparative Assessment of Impacts and Mitigation Actions



Two bar graphs support a comparative assessment of the change in risk resulting from impacts and selected management actions, for the defined solar project. The top bar shows the overall estimated increase in risk from project impacts (red, to the right) and decrease in risk due to implementation of proposed management actions in the mitigation package (blue, to the left). The lower bar graph provides a detailed comparison by stresses or population effects. The red bars (right side) show the estimated increase in risk due to project impacts, and the blue bars (left side) show the estimated decrease in risk due to management actions.

Source: Desert Tortoise Recovery Portal

6.3.2 Second Workflow: Land or Wildlife Manager, Scientist, or Stakeholder

Through the map interface and dashboards of the Risk Reporter tool, users can explore the spatial nature of current risks to the population and how recovery actions included in a proposed project mitigation package may affect these risks. This user could employ the new Risk Reporter tool to investigate which threats, stresses, and population effects are contributing to risk within a particular area. This information can help these users evaluate what recovery actions may be most appropriate where and whether proposed recovery actions will be effective where they have been proposed. The specific tools that support this workflow, and the remaining user wokflows below, are described in more detail in Appendix C .

6.3.3 Third Workflow: Land Managers

A land manager uses the Recovery Action Designer and Recovery Action Tracker to add descriptions, actual locations, and extents of recovery actions being implemented on the ground. These can be compared with the proposed area and location for these actions, as designed in the original mitigation package, to track whether or not proposed mitigation was completed. In addition, the Tracker tool can be used to record indicator values from subsequent monitoring visits, so that the effectiveness of a recovery action can be evaluated over time. Through integration with the Desert Tortoise SDSS data management system, implemented recovery actions recorded in the Tracker allow for updating the risk maps (initially with forecasted decrease but eventually with observed changes). The Tracker also then removes these funded and implemented recovery actions from the list of potential (designed but unfunded and unimplemented) recovery actions available for future mitigation in the first user workflow.

6.3.4 Fourth Workflow: Project Team System Maintenance and Data Management

As mentioned previously, the project team uses the Data Explorer and Model Explorer to review, update, and add to the existing conceptual model and datasets of the Desert Tortoise SDSS. While this workflow is "behind the scenes" it is vitally important to the system utility both now and into the future. A great part of the utility and credibility of this system depends on its use of the best available data, models, and scientific knowledge related to desert tortoise recovery. The project partners strongly recommend that any future development of the system include, as one task, dedicated resources to continue the ongoing maintenance and updates to system data and models.

6.3.5 Fifth Workflow: Adapting the System for Other Species and Renewable Energy Types

The current SDSS focuses on the Mojave desert tortoise and on solar energy development projects. However, the conceptual modelling, spatial methods and system framework could be applied to other regions, sensitive species (e.g., Mohave ground squirrel), and renewable energy technologies (e.g., wind, geothermal). The system architecture can incorporate new inputs (data, information, knowledge) produced by other planning efforts and research. Scientists can use the Conceptual Model Manager (Murphy et al. 2013), for example, to develop a conceptual model for other priority species or regions (Darst et al. 2013). These users could then employ other system tools to conduct threats assessments and identify recovery actions for potential development projects.

What makes this adaptability possible is that the conceptual model is based on an open standard lexicon for biodiversity conservation. Developed by a group of conservation experts headed by Nick Salafsky (Salafsky et al. 2008), this lexicon was adopted by the Conservation Measures Program (CMP 2015). As part of this project, the partners formalized that lexicon as a domain ontology within the spatial decision support ontology available at the public Spatial

Decision Support Knowledge Portal (SDS Knowledge Portal; Li 2012). The Desert Tortoise SDSS conceptual model was then formalized as a modified subclass of that biodiversity conservation domain ontology. This provides researchers with access to both the biodiversity conservation lexicon, and the desert tortoise conceptual model in a format that can facilitate adaptation of these frameworks for other species and regions. Appendix C provides more detail on this research task.

6.4 Discussion

Considering the five user workflows described above, two are already in use (the second and fourth) by the project team and the USFWS. The third workflow has received wide support from land and wildlife managers on the inter-jurisdictional desert tortoise Recovery Implementation Teams (RITs). The fifth workflow acknowledges that this system is adaptable and has tremendous potential for re-use by land managers and scientists for new species, regions, and energy development types.

The first workflow, intended to support project developers and designers, has been used (see Chapter 4) and tested by the project partners and provided useful information related to the probable impacts resulting from existing solar energy development projects and their potential mitigation packages. While the partners have envisioned and designed the system and Recovery Portal tools to support project developers and designers, this workflow has yet to be fully adopted by all those who might benefit from its use.

CHAPTER 7: Conclusions and Gap Analysis for Future Research

This chapter highlights identified areas for improvement in future iterations of the Desert Tortoise SDSS based on (1) priorities identified as part of the Energy Commission's EPIC Triennial Investment Plan; (2) the new Department of Interior mitigation strategy (California Energy Commission 2014; Clement et al. 2014); and (3) priorities identified through work completed in this project, including system reviews and uncertainty analysis.

7.1 How the System Addresses Priorities of the Energy Commission

The Desert Tortoise SDSS supports some of the specific priorities stated in the program strategies for the California Energy Commission EPIC 2014-2017 Triennial Investment Plan. The system:

- Addresses the need to resolve critical "scientific data gaps" and develop "analytical tools related to sensitive terrestrial species and habitats" including habitat suitability models.
- Provides "synthesis reviews of impacts of renewable energy development on species and habitats and of the relative success of mitigation strategies;"
- Provides tools for appropriate siting and planning of renewable energy developments; and
- Contributes scientific data and analysis to support specific renewable energy conservation planning efforts, e.g., through the DRECP.

7.2 Relationship to the Department of Interior Mitigation Strategy

The recently released U.S. Department of Interior (DOI) mitigation strategy (Clement et al. 2014) calls for a consistent, landscape-scale, science-based mitigation program of the lands and resources for which the Department is responsible. In order to realize the promise of landscape-scale mitigation, the Department and its bureaus will institute policies and procedures that reflect several guiding principles, including: landscape-scale, promote certainty, advance mitigation planning, science and tools, foster resilience, transparency, collaboration, and monitoring.

The Desert Tortoise SDSS is a tool for developing efficient and effective compensatory mitigation programs for impacts that cannot be avoided or minimized. The baseline risk and the increase-in-risk calculations in the Desert Tortoise SDSS provide a solid foundation for understanding the status and drivers of change to endangered species within the proposed development area. The decrease-in-risk from recovery actions calculation provides a basis for evaluating the tradeoffs associated with alternative mitigation strategies, because all pieces of a mitigation proposal are evaluated on the same scale in terms of their benefit to the species. The system could be improved by incorporating ways to measure project impacts to evaluate and improve the increase-in-risk calculation and monitoring to understand the effectiveness of mitigation actions relative to their predicted decrease-in-risk.

The following paragraphs illustrate how the Desert Tortoise SDSS relates to priorities identified in the DOI mitigation strategy.

Landscape-scale. The Desert Tortoise SDSS provides a tool to assess existing and projected landscape conditions, particularly identifying landscape-scale issues, threats, and impacts. The benefits of recovery actions for mitigation are evaluated based on their ability to ameliorate the existing threats and impacts. The system could be improved if more explicit management goals and strategies for the landscape were incorporated, such that monitoring and evaluation could take place in an adaptive framework.

Promote certainty. The SDSS provides scientific information and tools for assessing baselines and evaluating proposed impacts and mitigation options within that landscape. The structured, repeatable analyses conducted within a user-friendly framework can ensure mitigation decisions are principled and consistent rather than ad hoc.

Advance mitigation planning. The SDSS provides a tool for all of the involved partners, project proponents, planners, and reviewers, to evaluate the impacts of the proposed actions early in the project development process. The SDSS can help these partners identify the most efficient and effective means of mitigating the effects of development on the Mojave desert tortoise and to inform monitoring and evaluation of mitigation efforts. The utility of the SDSS for advanced planning could be improved with an enhanced "Prompt Workflow" for all involved partners.

Science and tools. The system provides a detailed understanding of the current baseline status of the resource necessary to develop landscape-scale strategies, compare mitigation scenarios, and assess the effectiveness of mitigation actions over time. The system would be improved by continuing to incorporate the impacts of projected as well as existing threats, such as the impacts associated with climate change, invasive species, or changing fire regimes.

Foster resilience: The SDSS helps to provide opportunities to build resilience by considering the cumulative effects of development and incorporating conservation principles such as habitat connectivity. The system's contribution to resiliency analyses would be greatly improved by further investigations into anticipating and preparing for shifting wildlife movement patterns; maintaining key ecosystem services; and preventing the spread of invasive species.

Transparency: The SDSS promotes transparency and consistency in the development of mitigation measures. The SDSS analyses clearly state the resource values and functions for which mitigation is being implemented, and the resource values and functions that are benefiting from the mitigation actions. The integration of GIS and other visual displays promotes understanding of model composition, calculations, and results.

Collaboration: The SDSS provides a tool to facilitate coordination among the research team and other partners and stakeholders, such as other federal and state agencies, tribes, and stakeholders, in conducting assessments of existing and projected resource conditions, forming mitigation strategies, and developing compensatory mitigation programs for the Mojave desert tortoise. The system's utility would be enhanced by collaborating with the larger networks of Landscape Conservation Cooperatives, Climate Science Centers, and other partnerships, which could provide essential information in the development of landscape-level mitigation strategies across sectors, scales, and levels of government.

Monitoring: The SDSS can inform monitoring and evaluation of mitigation efforts to ensure that the intended outcomes are achieved. The Recovery Action Tracking tool allows the input of management actions for planned mitigation and then change their status so that the research team and other partners and stakeholders can track mitigation action implementation. As part of the initial phases of project planning and in concert with project implementation, a monitoring strategy should be developed that permits accurate and transparent assessment of the current status of the resources of concern, how development has affected those resources, and progress in achieving the specific mitigation objectives for the resources and values impacted by the project. The system could be improved by monitoring and evaluation of impacts and mitigation strategies, the information from which could feed back into the system for model and data improvement.

7.3 Prioritized Research and System Improvements for Next Iteration

Based on findings from this project, the project team prioritized a set of desired improvements:

- Further research to estimate the viability of local populations based on updated assessments of landscape fragmentation, local risk factors, and population movement.
- Further research into understanding and modeling landscape-scale dynamics of population fragmentation and climate change, with a priority emphasis on identifying recovery actions that will be most effective across multiple climate change scenarios.
- Adaptation and application of the current decision support framework to multiple species of concern.
- Further research into the durability of various recovery actions, and the temporal effects of cumulative impacts on the viability and effectiveness of recovery actions.
- Developing conceptual and computational models for multiple key species in a region and identifying recovery actions that benefit multiple species and where best to locate them, and threats that impact multiple species, and where they are most harmful.

Table 23 describes key improvements for future iterations of the system.

Table 23: Priorities for Improvements to the Next Iteration of the Desert Tortoise SDSS

General Area	Specific component	Gaps observed from this project	Recommendations for future development
Collaboration tools	Expert Weights Elicitation	With our improved understanding of the model structure, and after many changes since the original expert weights were gathered, researchers need to conduct a new expert survey to obtain key parameters in the system.	Use online webinars to provide context for the SDSS, then conduct online weights surveys with results feedback.
Calculation Workflow for Project Developers	Solar Energy Development Impacts and RA Mitigation Calculator (Calculator)	There is currently no way to manage, reuse and edit mitigation packages at the package level. This inhibits reusability of simulations.	Provide a full-fledged mitigation package manager.
Calculation Workflow for Regulators	Calculator	There is no capability to compare two Solar Project impacts. This makes it cumbersome to determine if design refinements are effective.	Add the capability to the Calculator to compare impacts from two projects, including two alternative site locations of a single project, and mitigation from two management action packages.
Calculation Workflow for Researchers	Scenario Manager	The scenario manager does not encompass the raw input data sets, but instead only reaches as far as the derived threat layers.	Extend the scenario management to the input data sets, and let the user of the Calculator specify which scenarios they want to work with.
Model Structure	Conceptual model	Integrating landscape structure with demographics stresses has to move beyond linear contributions.	Develop a computable model that better combines structural and demographic factors
Recovery Action submodels	Climate Change Scenarios	Do TCAs and protected corridors need to be redefined to allow for anticipated changes?	Use USGS climate change based habitat potentials to explore spatial shifts in threat intensities over time.
	RA Designer Calculations	Currently the RA Designer captures sufficient detail to auto-	Prioritize Recovery Action Types by region, and develop design

General Area	Specific component	Gaps observed from this project	Recommendations for future development
		calculate risk reductions only for 6 of the 26 Recovery Action types	models for the next 3-5 most important recovery action types.
Overall Model Structure	SDS Engine	Need a way to update Population Capacity in real time	Implement patch level algorithms to update locally in real time. Acquire algorithms to update range wide population capacity.
Uncertainty Analysis for spatial threats data	SDS Engine	Need a computationally feasible approach that handles variations in dozens of spatial input layers to be incorporated into the Calculator	The input threat layers do not change frequently, so could connect system to High Performance Computing systems (e.g., CyberGIS) and precalculate and store outputs for many combinations
Uncertainty Analysis for RAs with large effects areas	SDS Engine	Need a computationally feasible approach that deals with mismatch in scale between actions and impacts	Develop approximate methods AND connect system to High Performance Computing systems (e.g., CyberGIS)

7.4 Conclusions: Looking to the Future

The research conducted in developing the Desert Tortoise Spatial Decision Support System has provided valuable support to regulators, planners, and project reviewers charged with meeting environmental protection and renewable energy development goals in the Mojave Desert. With the conclusion of this Energy Commission grant, a chapter is closing in the development of the Desert Tortoise SDSS and Recovery Portal. The closing of this project coincides with changes in the project team that may present challenges to the future management and development of the system.

While a number of stakeholders and land managers recognize the utility of this system, and are eager to see it applied to other species and development types, it may become necessary for one of them to step up and take ownership of the future development and application of the system. Given current funding and political realities, the project team would encourage a broad conversation among stakeholders, including both current and future beneficiaries of the system, about how the research completed under this project can best be integrated with future efforts, including the ongoing development and implementation of the Desert Renewable Energy Conservation Plan.

Whether or not the system continues to be used in its current form, this research has provided many valuable insights into the scientific and management challenges in evaluating environmental impact of renewable energy development on protected species. By leveraging new software technologies, the project partners have demonstrated that complex spatial tools can be deployed on the web for a variety of users to estimate risk implications for a species in real time. The approach and models used in this research have great potential for adaptation and application to other species, regions, and types of renewable energy. The Desert Tortoise Spatial Decision Support System constitutes a springboard that other researchers may use to advance their work on building assessments of impact to support and inform environmental review of renewable energy development.

GLOSSARY

Term	Definition
Altered habitat potential (AHP)	A data layer that quantifies resistance to tortoise movement across the entire desert tortoise range. This layer was derived from USGS habitat potential surface by removing impervious surface areas and using expert assessment of anthropogenic impacts on habitat potential. See Section 3.3.
BLM	Bureau of Land Management
Carrying capacity	For a given region, carrying capacity is the maximum number of individuals of a particular species that resources can sustain indefinitely without significantly depleting or degrading those resources. For example, threats to habitat may not result in direct mortality of individuals, but changes to carrying capacity which result from impacts to habitat can affect population numbers.
Combined impacts / combined effects	All of the direct and indirect effects resulting from a specific threat. For example, New solar energy developments present direct threats (e.g., "Habitat destruction") and indirect threats (e.g., "New roads"), the totality of which represent the combined impact of this activity on desert tortoise.
Computational model	Models containing mathematical equations or algorithms that simulate natural processes and use a set of input parameters to predict the outcome of these processes. For example, The SDSS computational model expresses the elements and input parameters of the conceptual model as algorithms, which are then executed using GIS and other software programs.
Conceptual model	A representation of the set of causal relationships between factors that are believed to affect an at-risk species (Darst et al. 2013). For example, the Desert Tortoise SDSS uses a conceptual model to characterize the interrelationships among threats, tortoise population declines, and recovery actions.
Conservation action	Interventions undertaken to reach conservation goals and objectives (Salafsky et al. 2008). See Recovery Actions.
Demographic factors	The combination of population effects (mortality, reproductive output and immigration/ emigration) with tortoise life stages (juvenile and adult). The four demographic factors in the conceptual model are: change in adult mortality, change in juvenile mortality, change in reproductive output, and change in immigration/ emigration.
Direct effects of a threat	Pathways from threats to stresses to associated population effects on population risk (Darst et al. 2013). For instance, the effect of (the threat of) "Ravens" on (the stress of) "Predation" leads to (the population effects of)

	Adult mortality and Juvenile mortality
DRECP	Desert Renewable Energy Conservation Plan
DTRO	Desert Tortoise Recovery Office of the U.S. Fish and Wildlife Service
Effectiveness weight	An estimate of how effective a recovery action is in suppressing a threat or a threat-stress mechanism. For example, a tortoise fence erected on both sides of a road can eliminate crushing due to motor vehicles on the road (an effectiveness weight of 1).
Fragmentation / Population fragmentation	The fracturing, reduction in size and/or loss of connectivity between habitat patches and the populations they support. See Chapter 3 for a description of various approaches to modeling population fragmentation in this project.
FWS	U.S. Fish and Wildlife Service
GIS	Geographic Information System
Habitat Suitability	A model for predicting the suitability of habitat for a species based on its preferred environmental parameters.
ISEGS	Bright Source's Ivanpah Solar Energy Generating System
Layer	A surface on a map that when interrogated returns a value (often null) for any point on the map
Link	An effect that connects two objects, represented visually as line connecting two nodes
OAT	One-at-a-time Sensitivity Analysis
Output Variance Decomposition	An approach to uncertainty analysis used to estimate the sensitivity of system output uncertainty to the components' variability (Saltelli et al. 2010). See Section 1.3.4.
PIER	Public Interest Energy Research program of the California Energy Commission
Population Capacity	A metric that combines metapopulation and individual territory models for population dynamics. Population capacity λ_P is the principal eigenvalue of the connection Matrix M. A metric used in research exploring population fragmentation; see Section 3.5.2.
Population effect	Change in mortality, reproductive output, or immigration or emigration in a population (Darst et al. 2013); for example, change in mortality among juvenile tortoises.
Probability of Connection	A general metric for fragmentation of habitat patches that considers patch value and probability of travel between specific patches. A metric used in

Index (PCI)	research exploring population fragmentation; see Section 3.5.1.
Probability of presence (POP)	A map layer representing the current probability of presence of the desert tortoise, as derived from the USGS habitat potential model after removing any impervious (paved, urban) surfaces. For instance, the value of the probability of presence surface at a point indicates how suitable that area is for the desert tortoise. For those areas that have a high (close to 1) value but currently no desert tortoise population, a population may return and thrive there in the future, a critical consideration in terms of species recovery.
Raster data	GIS raster data is structured as an array of square cells (pixels) in geographic coordinate space where each pixel is coded with a single value (potentially more values based on format and data type constraints). For example, elevation data may be encoded as a raster or continuous data surface.
REAT	Renewable Energy Action Team
Recovery	The process by which the decline of an at-risk species is arrested or reversed so that its long-term survival in nature can be ensured (Darst et al. 2013)
Recovery action	A management action taken in support of desert tortoise recovery (Darst et al. 2013). For example, tortoise fencing along roads is a recovery action designed to reduce mortality of tortoises from on-road traffic collisions.
Resilience	The likelihood of a particular tortoise patch (represented as hexagonal cells) being "rescued" from extinction by the combined effort of all other cells in the range. A metric used in research exploring population fragmentation; see Section 3.8.2.
Resistance to movement	The willingness of an organism to cross a particular environment, the physiological cost or the reduction in survival for the organism moving through that environment, or a combination of these factors. A metric used in research exploring population fragmentation; see Section 3.3.
Risk to the population	Aggregate stress due to threats X Probability of Presence. The system multiplies (1) the relative impact of threats and relative effectiveness of recovery actions based on their predicted effect on risk to the population, by (2) probability of presence in order to calculate risk to the population at each point across the range of the tortoise.
RIT	Recovery Implementation Teams for the Mojave Desert Tortoise
SAC	Science Advisory Committee to the FWS Desert Tortoise Recovery Office
Scenarios	Formal versioning of the data, recovery action tracking, and user comments from system component tools such as the Data Explorer and Model Explorer, as well as system inputs and outputs for particular computational

	runs. In the SDSS, each system run has a unique scenario associated with it, its inputs and its outputs, so that project partners can compare results between system runs over time and even re-run a particular scenario or system version if necessary.
SDSS	Spatial Decision Support System
Sensitivity analysis	Sensitivity analysis answers the question of which model components' variability (e.g., variability in inputs, weights, and/or parameters) are most responsible for system outcome uncertainty. For example, changing the contribution weight of (the threat of) "Ravens" to "Predation" changes the estimate of the risk to the population.
Spatial decision support system (SDSS)	A method for breaking down a large problem into its component parts and identifying how those parts interact (Starfield 1997). The Desert Tortoise SDSS is one example.
SSA	Spatial Sensitivity Analysis
STEP	Siting, Transmission, and Environmental Protection division of the California Energy Commission
Stress	Degraded condition or "symptoms" of the species that result from a threat (Salafsky et al. 2008). An example is (the stress of) "Toxicosis" is the mortality or sublethal effects in the population due to effects of a poison or toxin.
TCA	Tortoise Conservation Area
Threat	Naturally occurring or proximate human activities that have caused, are causing, or may cause the destruction, degradation, or impairment of species (Salafsky et al. 2008); e.g., Urbanization, Military operations, Paved Roads.
Threat intensity layer	A range-wide map layer whose value at each point represents the intensity of a specific threat at that point. For example, the density of urbanization within the tortoise range.
Threats assessment	A systematic approach to assessing the relative importance of each threat to a species' status (Darst et al. 2013). By using the system estimates of relative contributions of a specific threat in an area, the threats present in that area can be ranked.
Uncertainty analysis	Uncertainty analysis attempts to characterize the uncertainty (variability) in the outputs of a system based on knowledge of the uncertainty (variability)

	of the inputs and model parameters of the system. Uncertainty in outputs of a system is often characterized by the use of error bars.
USGS	U.S. Geological Survey
Weight	The quantified relative contribution of one node in the conceptual model to another node, as in the contribution of a threat to a particular stress (threat-stress link). For example, the quantified "weight" or relative contribution of the threat of "Ravens" to the stress of "Predation."

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USEFUL RESOURCE LINKS

California Energy Commission website: http://www.energy.ca.gov/

Desert Managers Group: http://www.dmg.gov/

Desert Renewable Energy Conservation Plan: http://www.drecp.org/

Desert Tortoise Council: http://www.deserttortoise.org/

Desert Tortoise Preserve Committee: http://www.tortoise-tracks.org/

Desert Tortoise SDSS Data Explorer: http://www.spatial.redlands.edu/dtro/dataexplorer

Desert Tortoise SDSS Model Explorer: http://www.spatial.redlands.edu/dtro/modelexplorer/

Desert Tortoise SDSS Recovery Portal: http://www.spatial.redlands.edu/cec

Fish and Wildlife Service, Desert Tortoise Recovery Office:
http://www.fws.gov/nevada/desert_tortoise/

Mojave Desert Ecosystem Program (MDEP): http://www.mojavedata.gov/

APPENDICES

The following appendices are available as a separate publication, publication number: CEC-500-2016-065 -APA-C

APPENDIX A: Data Inventory for the Desert Tortoise Spatial Decision Support System (SDSS)

APPENDIX B: Report to the Renewable Energy Action Team, Sept 2013: Applying a Spatial Decision Support System to Calculate Mojave Desert Tortoise Mitigation Action Ratios for the Desert Renewable Energy Conservation Plan

APPENDIX C: Additional Details on Desert Tortoise Spatial Decision Support System (SDSS) Improvements